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An Analysis of the Performance of
Typical Steam Locomotives

Railway Mechanical Engineering

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AN ANALYSIS OF THE PERFORMANCE OF TYPICAL STEAM LOCOMOTIVES

BY

HAROLD ALLEN HOUSTON

B. S. Purdue University, 1911

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

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IN RAILWAY MECHANICAL ENGINEERING

IN

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OF THE

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DEGREE OF MASTER OF SCIENCE

Edward C. Schmidt In Charge of Major Work

Edward C. Schmidt Head of Department

Recommendation concurred in:

Committee
on
Final Examination

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AN ANALYSIS OF THE PERFORMANCE
OF TYPICAL STEAM LOCOMOTIVES.

By Harold Allen Houston

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AN ANALYSIS OF THE PERFORMANCE
OF TYPICAL STEAM LOCOMOTIVES.

AN ANALYSIS OF THE PERFORMANCE OF TYPICAL STEAM LOCOMOTIVES.

In the field of railway operation it is known that the electrical engineer can predetermine the operating characteristics of his motive power to such preciseness that accurate and intelligent estimates of schedule speed, frequency of stops, distance traversed, power consumed, etc. can be made for any given condition. For the mechanical engineer, the predetermination of the operating characteristics of steam locomotives is an uncertain attempt to enjoy the benefits now possessed by the electrical engineer.

The purpose of this article is to study and exhibit the laws governing the variation in steam locomotive performance, and so to adapt them that an approach can be made to the degree of accuracy obtained in electrical operation when considering motive power characteristics; and finally, to compare the analytical results with practice for selecting certain locomotives for a particular kind of service.

It is necessary, therefore, that the characteristics of different types of steam locomotives be thoroughly understood, as an incorrect analysis of a fundamental law might lead to erroneous conclusions. For this reason, steps have been taken to investigate the various factors pertaining to steam locomotive and steam train operation. The location

and subject of each factor is as follows:

(a) Appendix I, Steam Locomotive Tractive Effort.

(b) Appendix II, Machine Friction of the Locomotive.

(c) Appendix III, Train Resistance.

(d) Appendix IV, Speed-time curves.

(e) Appendix V, Water and Coal Consumption.

In the investigation of a problem of this kind, it must be borne in mind that a measure should be adopted which will give enough flexibility, first, to permit a determination of the operating characteristics of several steam locomotives, and second, to offer a means for the comparison of these locomotives with each other on a basis of performance.

A general statement can be made that most railroads base their estimates of operation upon the capacity of the rolling stock, as this determines the motive power, the schedule speed, the water and coal consumption, and finally, the cost of operation.

Now to make the application of this scheme feasible, four typical steam locomotives of various types and power have been selected. Their horse-power has been calculated on the assumption that I.H.P. = 0.43 x Heating Surface. On page 7 is a table which gives the principal dimensions of these locomotives. It should here be noticed that two of these locomotives have what we will term large driving wheels and two of them have small driving wheels. The distribution of

TABLE I.

PRINCIPAL DIMENSIONS of TYPICAL STEAM LOCOMOTIVES.

	(1)	(2)	(3)	(4)
Nominal H.P.	800	1000	1500	1500
Type	4-4-0	2-8-0	2-8-2	4-4-2
Road	NYCHR	CRI&P	CM&PS	P.RR.
No.	999	1720	2502	5075
Builder	NYCHR	B.L.W.	CM&SP	P.RR.
Date	1892	1907	1909	1911
Sim.or Comp.	S.	S.	S.	S.
Wt. Total	124000	198600	260500	231500
Wt.on Driv.	84000	177300	201300	133300
Wt.on L.Trk.	40000	21300	25500	51270
Wt.on T.Trk.	-	-	34000	46930
Wt.Tend.Ld'd.	204000	238900	414500	389500
Dia. Driv.	86"	63"	63"	80"
No. of Cyl.	2	2	2	2
Dia. of Cyl.	19"	23"	24"	22"
Stroke	24"	30"	30"	26"
Stm.Pres.Lbs.	190	185	200	205
H.S.-Tubes	1697	2427	3332	3364
H.S.-F.B.	233	168	282	218
H.S.-Total	1930	2595	3614	3582
Coal Cap.-tons.	6.75	12	14	-
Water Cap.-Gal.	3587	7000	8000	-

the total weight of each locomotive is shown by Fig. 1 on page 9. The variation in the heating surfaces is shown by Fig. 2 on page 9.

Locomotives Nos. 1 and 2, which have only a difference of 200 H. P. in their rating, show a decided difference in weight on drivers and less difference in total weight; locomotives Nos. 3 and 4 which are equal in horse-power, have a small difference in their total weight and a large difference in the weight on drivers. In either case, it is noticeable that the two small-wheel locomotives are relatively heavy on the drivers and the large-wheel locomotives are relatively light on their drivers.

The tender draw-bar pull for all speeds for these four locomotives is shown graphically by Fig. 3. The curves in this figure, which apply only to the engines under consideration, represent the maximum tractive effort available at the tender draw-bar. Each curve has been calculated by equation 9, which is derived in the second section of Appendix I.

The maximum ordinate of these curves is dependent upon the size of cylinders, driver diameter, steam pressure, etc. when the coefficient of adhesion between the drivers and the rail is sufficient to prevent slipping, otherwise the limit is found when the tractive effort reaches the adhesion of the locomotive. The extent of these curves to the right is limited by an arbitrarily fixed maximum, which is, that the speed limit for the small wheel locomotives shall be 60 miles per hour, and for the large wheel locomotives 80 miles per hour.

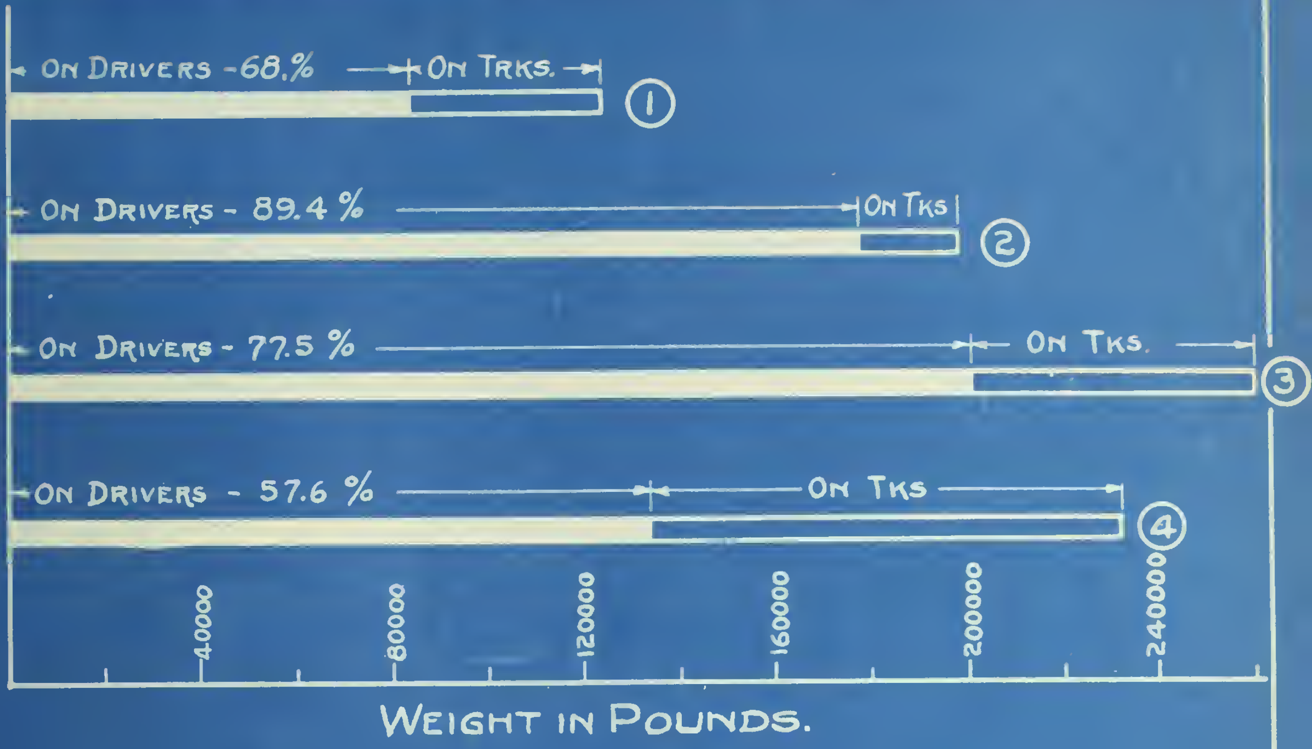


FIG. 1. WEIGHTS OF LOCOMOTIVES.

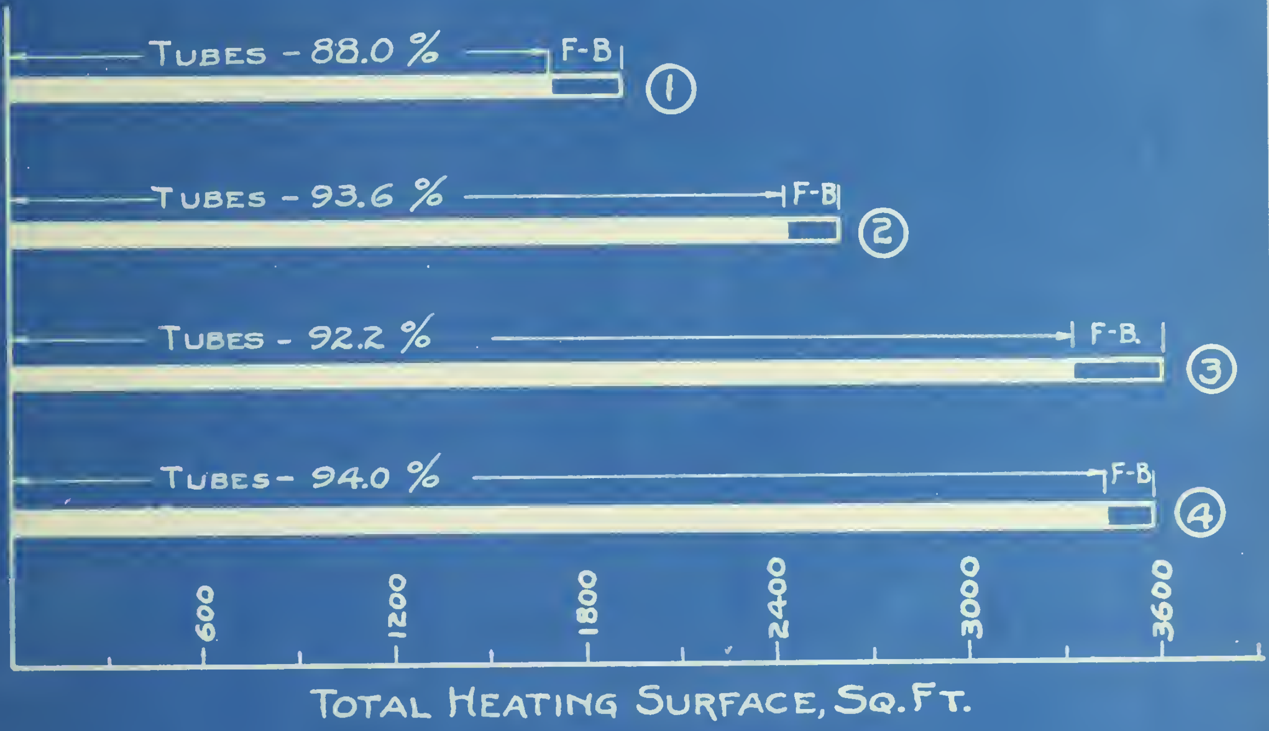


FIG. 2. HEATING SURFACES.

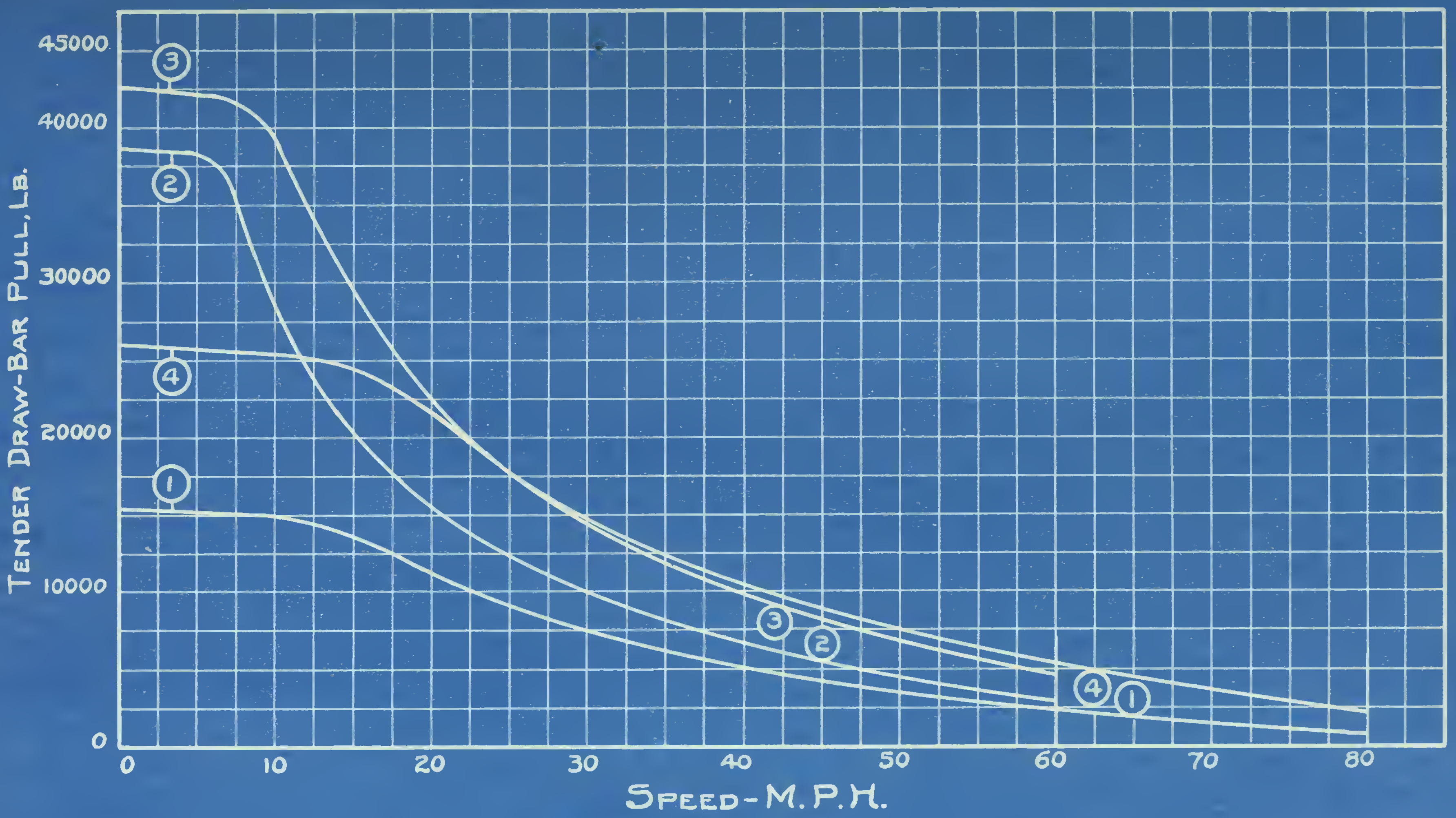


Fig. 3. Tractive Effort Curves.

Figure 4 is inserted in order that a better understanding may be had of the relation of weight to tractive effort for these locomotives. The numerals enclosed in the small circles are the numbers of the locomotives selected for this problem.

It is evident from the curves shown in Figure 4 that the large driving wheel locomotives have higher ratios of total weight to tractive effort at low speeds than the small driving wheel locomotives. But as the speed increases, this condition is reversed. This is probably more pronounced with locomotive No. 4, which maintains an almost constant ratio until a speed of about 30 miles per hour is reached, after which it rapidly increases. From this, it seems that high rates of acceleration can best be had at low speeds by the use of small driving wheel locomotives, as by locomotives Nos. 2 and 3, and that the large driving wheel locomotives are more suitable if high rates of acceleration are demanded at higher speeds.

A more detailed discussion on the subject of locomotive tractive effort is given in Appendix I. In this appendix a maximum rate of evaporation is taken which is below what might be considered a possible maximum rate. This consideration is made on account of the fact that for 10 or possibly 15 minutes the output of a locomotive boiler may be much beyond its normal maximum. This can be accomplished by not operating the injector and by keeping the fire door

closed as much as possible. Of course, the development of power under these conditions is exceptional, and therefore is not considered in the present discussion.

As before stated, it is proposed to study the operating characteristics of four typical locomotives. Up to this point, these locomotives have been subjected to an analysis to determine the number of pounds of horizontal pull that each is capable of exerting. It is now intended to study the performance of each of these locomotives when operating at the head of four different trains: first, on a local schedule, and second, on a through schedule.

These trains represent equipment that is typical of the service required, whether local or through, passenger or freight. The selection is as follows:

1. A train which has equipment typical of a standard local passenger run; a 200 ton train, consisting of 5 coaches, 80,000 lbs. each.
2. A train which has equipment typical of a standard through passenger run; a 600 ton train, consisting of 10 coaches of 120,000 lbs. each.
3. A train which has equipment typical of a mixed light freight train; a 1000 ton train, consisting of 45 cars of 44.5 tons (gross wt.) each.
4. A train which has equipment typical of a mixed heavy freight train; a 2000 ton train, consisting of 90 cars of 44.5 tons (gross wt.) each.

Fig. 5 has been inserted to present graphically a comparison of the relative weights of the different trains.

The freight trains have an arbitrarily fixed maximum

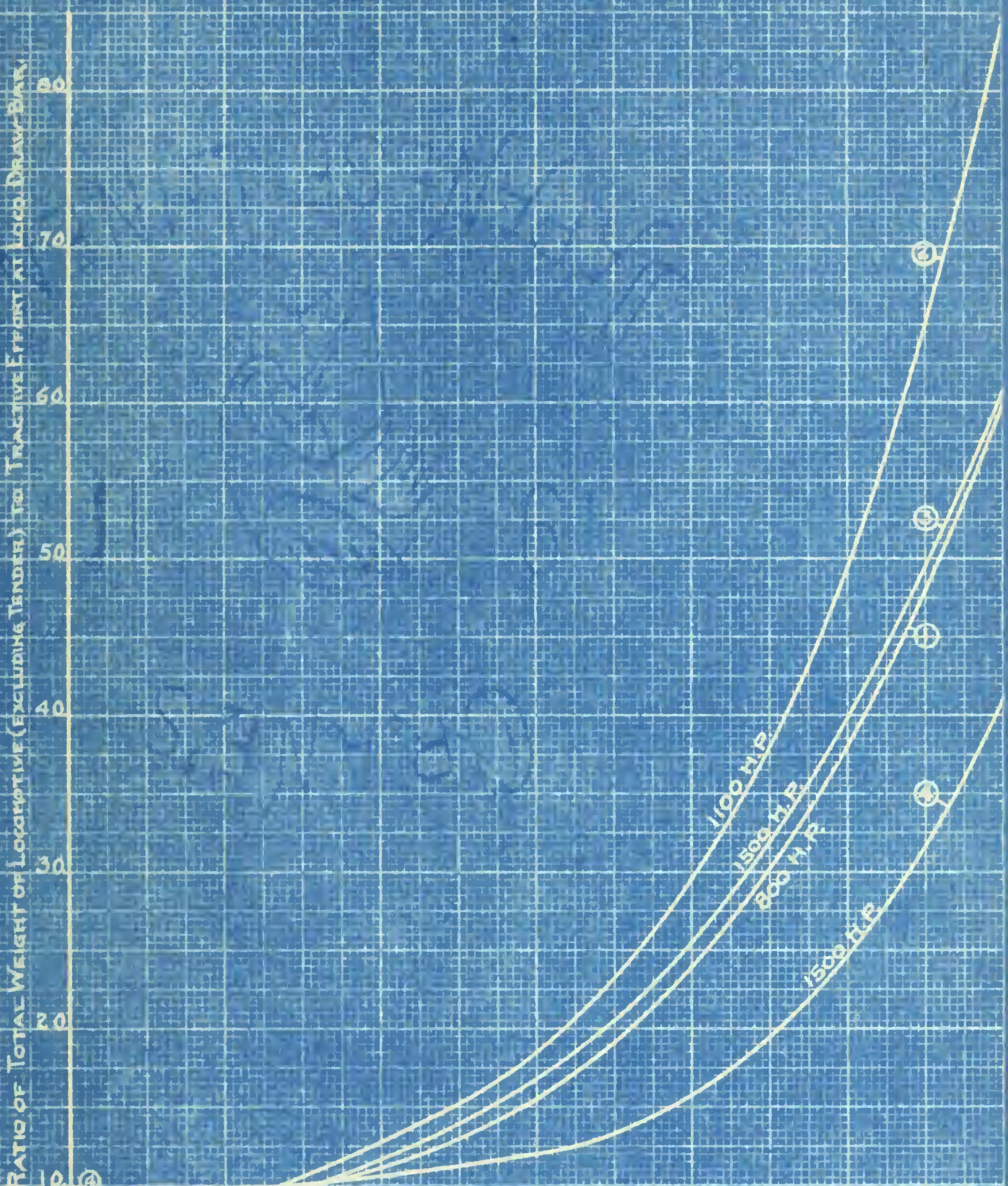


FIG. 4. SHOWING THE RELATION OF WEIGHT TO TRACTIVE EFFORTS FOR DIFFERENT LOCOMOTIVES.

U OF I S S FORM 3

speed limit of 40 miles per hour. For the passenger trains, this limit is 80 miles per hour.

In the attempt to provide typical operating conditions for the performance of the four selected locomotives at the head of the four selected trains, two hypothetical profiles of track are proposed, namely:

1. Profile of track with station stops characteristic of a local schedule.
2. Profile of track with station stops characteristic of a through schedule.

In either case, it is assumed that the track is straight, that no winds prevail, and that the stops are of no duration.

For the local schedule, the run is 50 miles in length on level track, as shown in Fig. 6, with station distances as follows:

Stations	Distance between consecutive stations. Miles.	Distance traveled from station "A". Miles.
A	0.0	0.0
B	0.5	0.5
C	1.0	1.5
D	1.5	3.0
E	2.0	5.0
F	3.0	8.0
G	4.0	12.0
H	5.0	17.0
I	7.0	24.0
J	10.0	34.0
K	16.0	50.0

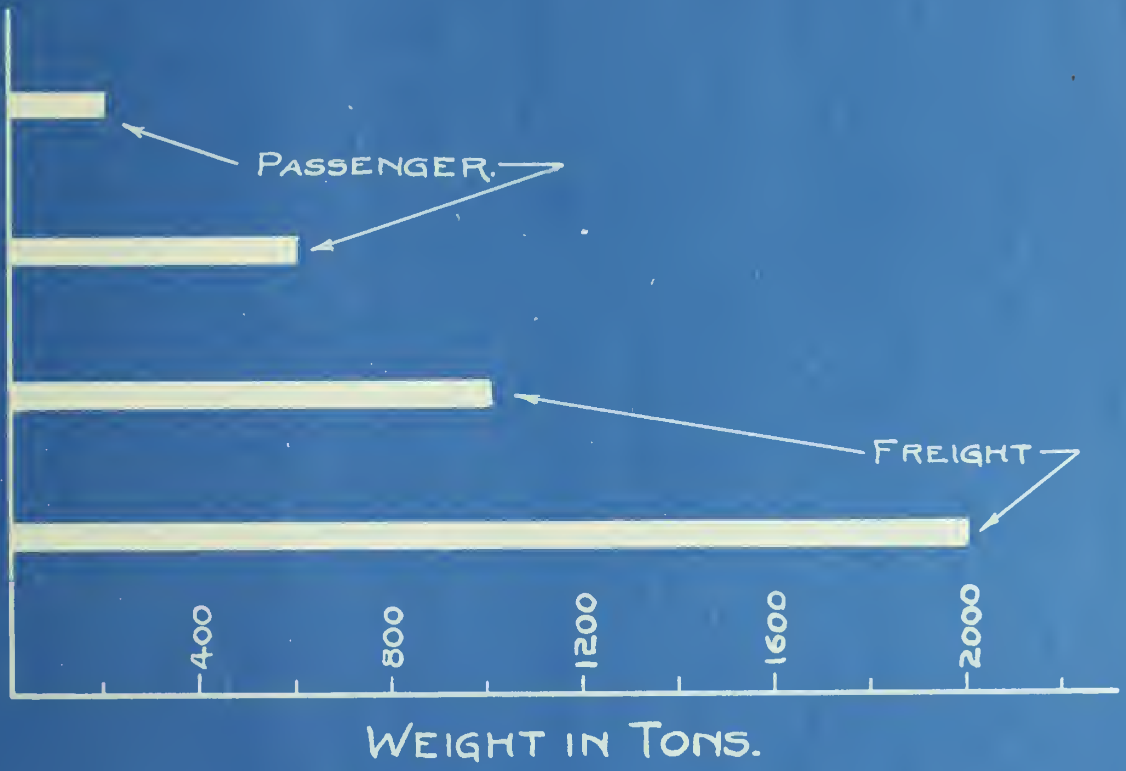


FIG. 5. WEIGHTS OF TRAINS.

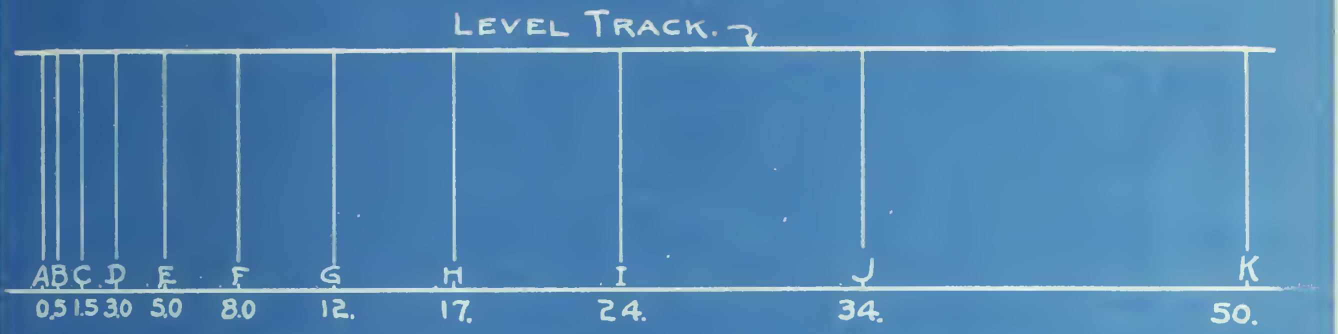


FIG. 6. PROFILE FOR LOCAL SCHEDULE.

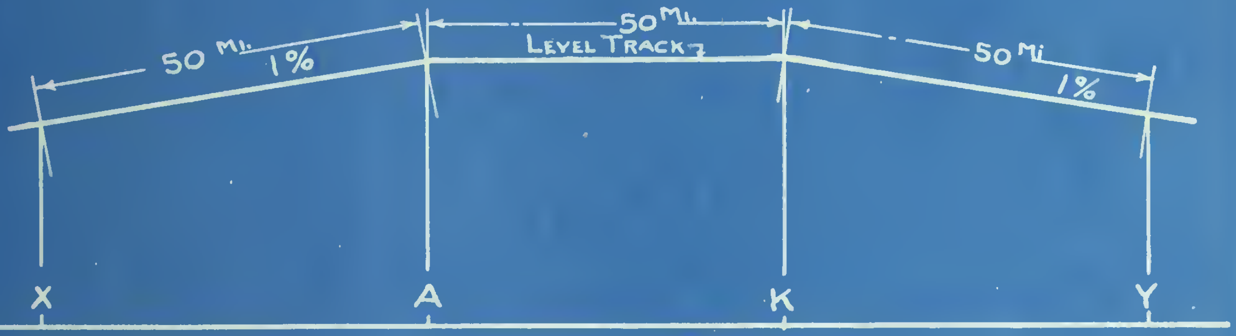


Fig. 7. Profile for Through Schedule.

For the through schedule, the length of run is 150 miles, as shown in Fig. 7, with stops 50 miles apart. In this case, it is assumed that the first fifty miles of track is 1% up grade, the second fifty miles level, and the third fifty miles 1% down grade. The station distances are as follows:

Distances for Through Schedule of Trains.

Stations	Grade	Distance between consecutive stations. Miles.	Distance traveled from station "X". Miles.
X		0.0	0.0
A	X-A is 1% up.	50.0	50.0
K	A-K is Level.	50.0	100.0
Y	K-Y is 1% down.	50.0	150.0

LOCAL SCHEDULES.

If we consider each of the four selected locomotives to operate at the head of each of the four trains on the local schedule, then a comparison of their performance can be made by determining the coal and water consumption, and the time required for each run. This has been done, and detailed discussions of the methods employed are given in Appendices IV and V. The results expressed in tabular form are exhibited in the following tables which are repeated in the appendices where their derivation is presented.

TABLE II.

TIME IN SECONDS FOR LOCAL SCHEDULE.

Stations	Distance between stations. Miles.	Locomotive Numbers							
		1	2	3	4	1	2	3	4
		200 Ton Train.				600 Ton Train.			
A	0	0	0	0	0	0	0	0	0
B	0.5	77	68	61	65	114	92	82	90
C	1.0	119	112	97	102	183	150	134	145
D	1.5	157	144	127	133	238	201	181	188
E	2.0	194	178	156	160	289	248	221	230
F	3.0	259	240	216	215	385	335	294	304
G	4.0	322	304	276	270	475	414	366	374
H	5.0	383	364	336	321	565	494	438	444
I	7.0	503	484	456	423	745	654	582	574
J	10.0	683	664	636	676	1015	894	798	770
K	16.0	1043	1024	996	982	1555	1374	1230	1160
		1000 Ton Train.				2000 Ton Train.			
A	0	0	0	0	0	0	0	0	0
B	0.5	149	118	100	114	223	150	134	159
C	1.0	230	190	160	181	353	246	215	246
D	1.5	300	250	214	235	410	323	286	322
E	2.0	363	308	271	285	558	398	350	390
F	3.0	484	412	362	374	745	544	472	511
G	4.0	604	515	452	464	925	688	592	631
H	5.0	724	618	542	554	1105	832	712	751
I	7.0	964	824	722	734	1465	1120	952	991
J	10.0	1324	1132	992	1004	2005	1552	1312	1351
K	16.0	2044	1748	1532	1544	3085	2416	2032	2071

TABLE III.

Water and Coal Consumption, for local schedule.

Stations	Distance between stops.	Water Consumed, lb.				Coal Consumed, lb.			
		Locomotive Numbers.							
		1	2	3	4	1	2	3	4
		200 Ton Train							
A	0	0	0	0	0	0	0	0	0
B	0.5	316	380	438	430	58	70	80	78
C	1.0	517	664	755	710	97	122	137	129
D	1.5	691	872	1020	960	134	159	186	174
E	2.0	865	1087	1275	1210	162	199	220	220
F	3.0	935	1509	1547	1680	224	276	254	306
G	4.0	1020	1938	1819	2160	280	354	288	393
H	5.0	1850	2364	2091	2640	338	432	322	480
I	7.0	2460	3194	2635	3600	543	584	398	655
J	10.0	3370	4444	3451	5040	618	812	500	917
K	16.0	5220	6934	5083	7920	952	1265	704	1440
		600 Ton Train							
A	0	0	0	0	0	0	0	0	0
B	0.5	491	577	756	688	91	105	138	124
C	1.0	835	972	1164	1184	154	177	212	215
D	1.5	1112	1303	1614	1576	204	238	296	286
E	2.0	1370	1628	1959	1968	251	297	357	357
F	3.0	1865	2215	2654	2656	342	405	484	482
G	4.0	2320	2755	3349	3316	424	504	610	602
H	5.0	2780	3310	4044	3974	509	604	737	721
I	7.0	3686	4415	5430	5176	677	807	990	940
J	10.0	5076	6075	7514	7050	931	1109	1368	1279
K	16.0	7856	9400	11664	10776	1437	1715	2127	1957

TABLE III (continued)

Water and Coal Consumption, for local schedule.

Stations	Distance between stops.	Water Consumed, lb.				Coal Consumed, lb.			
		Locomotive Numbers.							
		1	2	3	4	1	2	3	4
		1000 Ton Train							
A	0	0	0	0	0	0	0	0	0
B	0.5	577	681	1120	850	109	124	204	155
C	1.0	990	1145	1705	1335	182	209	310	243
D	1.5	1338	1538	2175	1816	237	281	396	330
E	2.0	1655	1920	2530	2260	303	350	460	411
F	3.0	2260	2640	3390	3100	415	482	617	564
G	4.0	2890	3350	4020	3960	529	612	710	654
H	5.0	3500	4063	4650	4820	646	742	803	744
I	7.0	4740	5490	5910	6540	867	1002	989	924
J	10.0	6590	7620	7800	9120	1206	1390	1268	1194
K	16.0	10290	11880	11580	14260	1880	2166	1826	1734
		2000 Ton Train.							
A	0	0	0	0	0	0	0	0	0
B	0.5	704	892	1185	755	137	164	218	137
C	1.0	1368	1538	1850	1741	237	281	341	289
D	1.5	1906	2060	2515	2254	357	378	464	409
E	2.0	2416	2571	3082	3146	450	471	568	567
F	3.0	3386	3585	4257	4038	627	656	785	734
G	4.0	4316	4578	5490	5176	796	839	1012	941
H	5.0	5656	5873	6647	6322	1059	1020	1213	1148
I	7.0	7096	7578	8965	8615	1303	1382	1634	1565
J	10.0	9876	10550	12420	12016	1808	1929	2264	2188
K	16.0	15406	16510	19350	18926	2823	3021	3533	3440

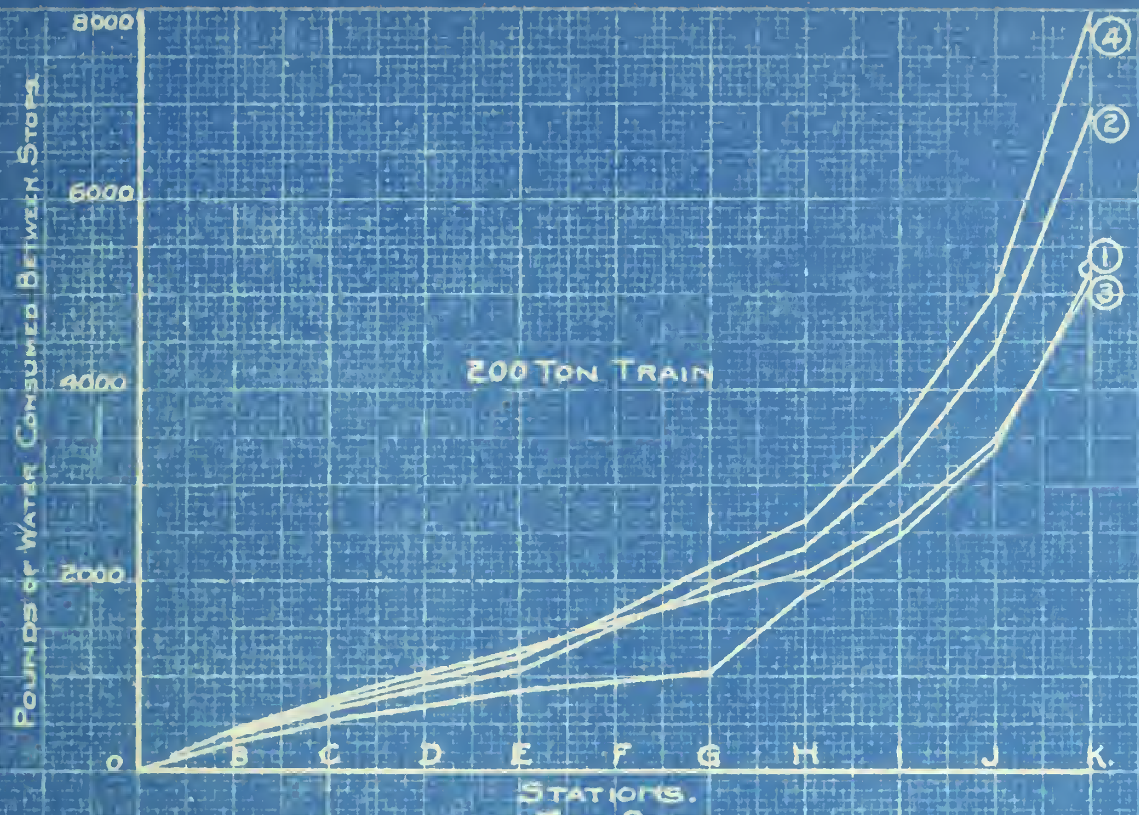
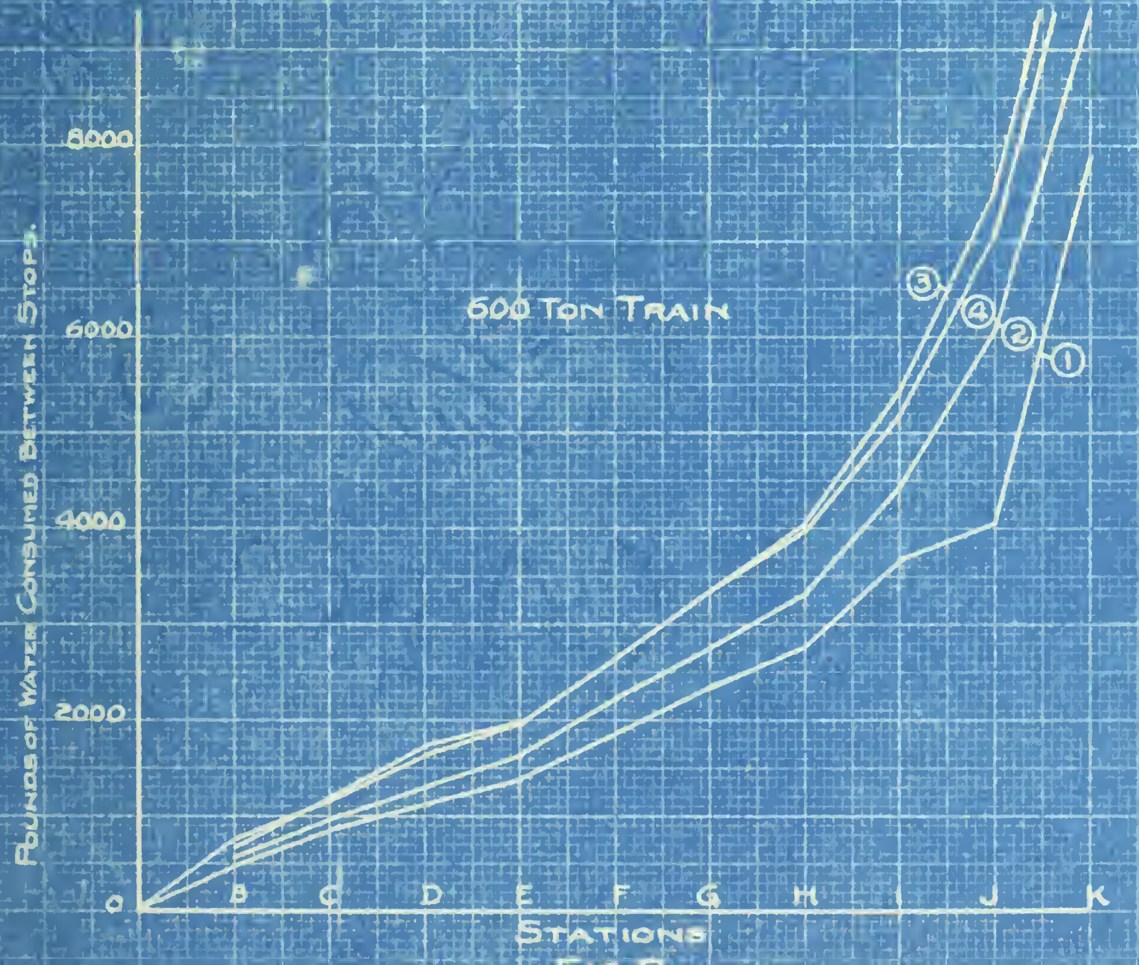

8000
6000
4000
2000
0
POUNDS OF WATER CONSUMED BETWEEN STOPS.
200 TON TRAIN
④
②
①
③
B
C
D
E
F
G
H
I
J
K.
STATIONS.

FIG. 8.


8000
6000
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0
POUNDS OF WATER CONSUMED BETWEEN STOPS.
600 TON TRAIN
③
④
②
①
B
C
D
E
F
G
H
I
J
K
STATIONS

FIG. 9.

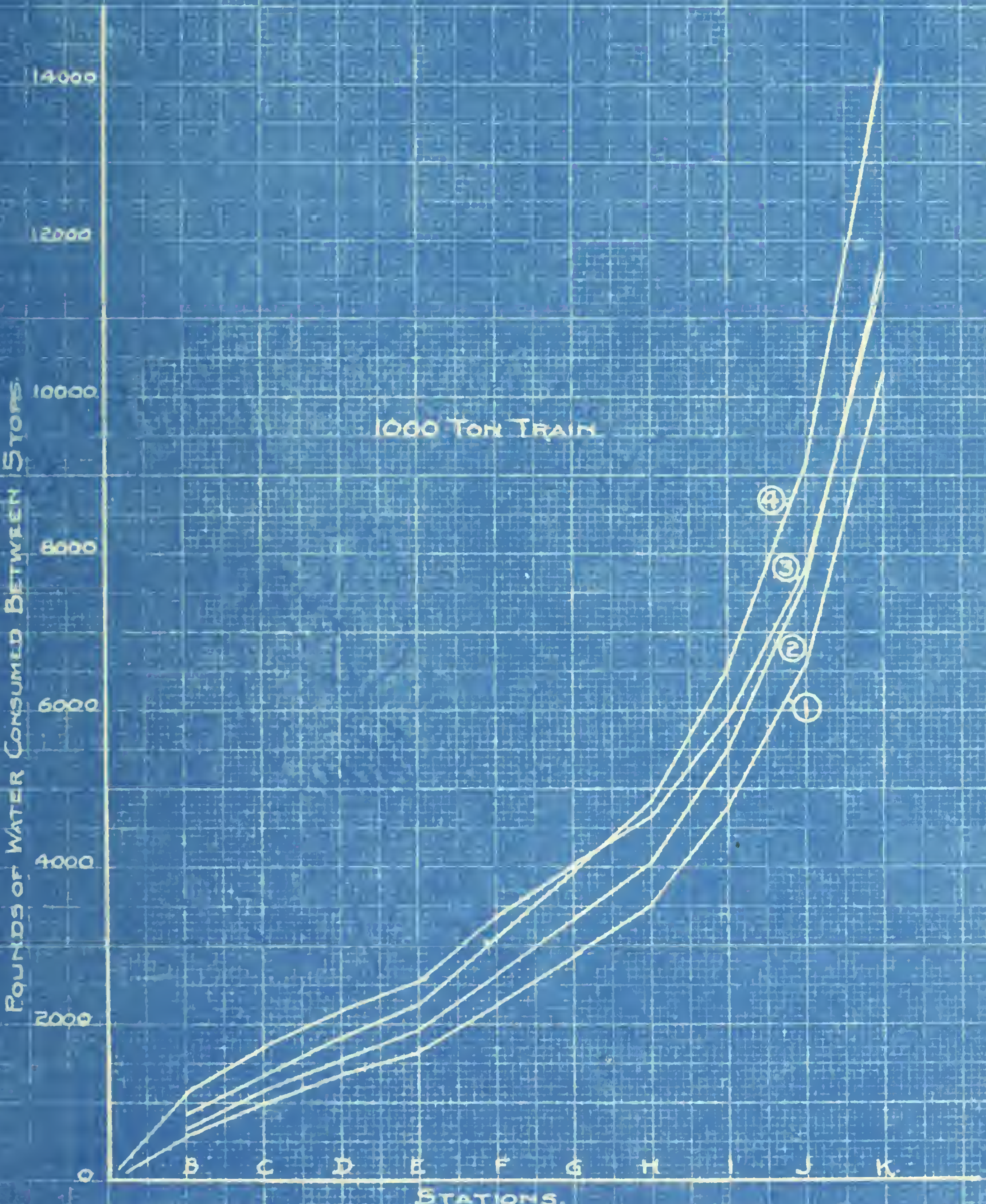
1000 Ton Train
Pounds of Water Consumed Between Stops
14000
12000
10000
8000
6000
4000
2000
0
B
C
D
E
F
G
H
I
J
K
Stations.
④
③
②
①

Fig. 10.

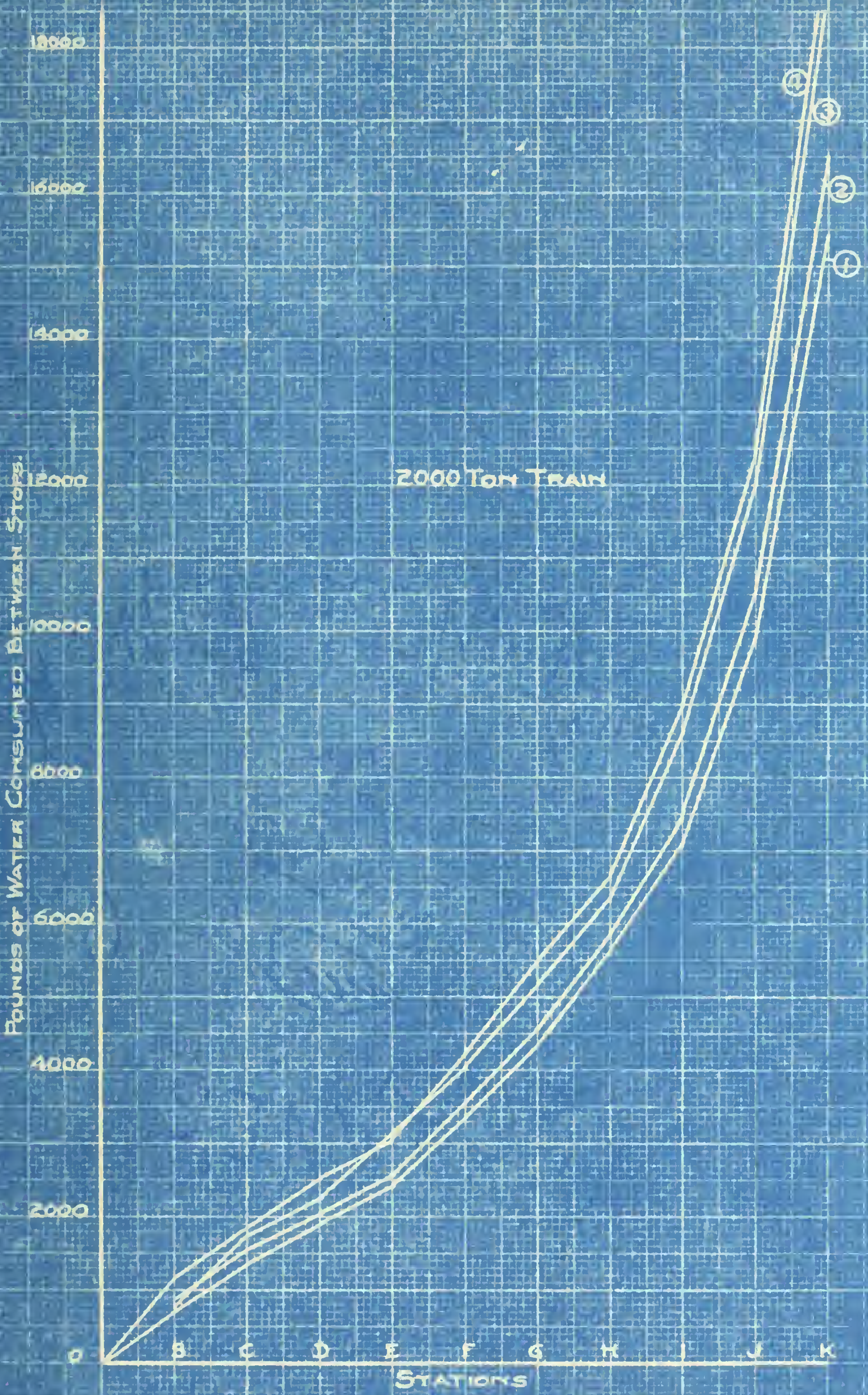
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
POUNDS OF WATER CONSUMED BETWEEN STOPS.
2000 TON TRAIN
④
③
②
①
B
C
D
E
F
G
H
I
J
K
STATIONS

FIG. 11.

The water consumption of each locomotive at the head of each train is well shown by Figures 8, 9, 10, and 11. In these figures the water consumption is shown for the distance traveled between the different stations, and not for the total distance from station A. The numerals enclosed in circles and placed near each curve, are to show that the curve in question represents the water consumed for that particular locomotive.

The writer has not attempted to show the variation of water consumption in terms of ton-miles, due to the fact that additional curves would tend to cloud the analysis rather than to clear it. Also, since each locomotive pulls the same four trains over the same distances, under identical conditions, further analysis on a ton-mile basis would be superfluous.

By comparing the curves shown in Fig. 8, the changes in the water consumption for the 200 ton train for the different station stops seem to be logical and uniform until Station E is reached; that is, with two locomotives of approximately the same power, the small wheel locomotive will consume the more water for a given distance and locomotives of different power will consume either more or less water, depending on the increment of increase or decrease in the power, and their wheel diameters, provided, of course, that operating conditions are the same. Beyond Station E it is seen that the water rate for locomotive No. 3 becomes relatively less and less until at Station K, which means a run of 16 miles with no stop, the

water consumption for a 1550 horse-power locomotive is less than for a locomotive of 830 horse-power, when both are operating under identical conditions. At first glance, this appears to be inconsistent, but by analysis we know that locomotive No. 3 must not exceed a speed limit of 60 miles per hour since it is of the small driver type, and by reference to the speed-time curves shown in Fig. 31, it is apparent that at the end of two miles this locomotive with a 200 ton train has accelerated to a speed of 60 miles per hour and is capable of going to a much higher speed. Since 60 miles per hour is the limiting speed, then this speed can be maintained for the remainder of run (minus the stopping distance) at less than maximum power. This is well shown by Fig. 35 in Appendix V. This decrease in the power is responsible for the apparent inconsistency in the water rate of locomotive No. 3.

By inspection of the water consumption curves for locomotive No. 3 and the 1000 ton train, as shown in Fig. 10, it is again seen that this 1550 horse-power locomotive has a lower water rate than locomotive No. 2, which is 1100 horse-power, when distances between stations are greater than 13 miles. This is explained in the same manner as when the locomotive was operating at the head of a 200 ton train, except that the limiting speed is now 40 miles per hour instead of 60.

Figures 9 and 11, which represent the water consumption for the different locomotives for the 600 and 2000 ton trains

respectively, show results which are to be expected and need no further discussion.

The fuel consumption curves for each of the four locomotives when operated at the head of the four trains, are shown by Fig. 12. In this figure it is to be noticed that the characteristics of the curves are similar to the water consumption curves, with the exception that when a locomotive is working at less than maximum power, the per cent drop in coal consumption is greater than the per cent drop in the water consumption, due to the greater evaporation per pound of fuel at less than maximum rates of power.

This is well illustrated in the case of the 200 ton train when it is propelled by locomotives Nos. 3 and 4. The water consumption for the last run in the local schedule is 2.7% less for locomotive No. 3 (1550 H.P.) than for locomotive No. 1 (830 H.P.); while the fuel consumption for the same run is 26.0% less for locomotive No. 3 than for locomotive No. 1.

A similar condition again appears with the 1000 ton freight train, while the other curves seem to be normal and in logical order. By logical order, it is assumed that if two locomotives of equal power but of different sized drivers, are worked to a maximum at the head of the same train under like conditions of operations, then the water and coal consumption would be greater for the small wheel locomotive than for the larger. A study of the water and coal consumption curves verifies this statement.

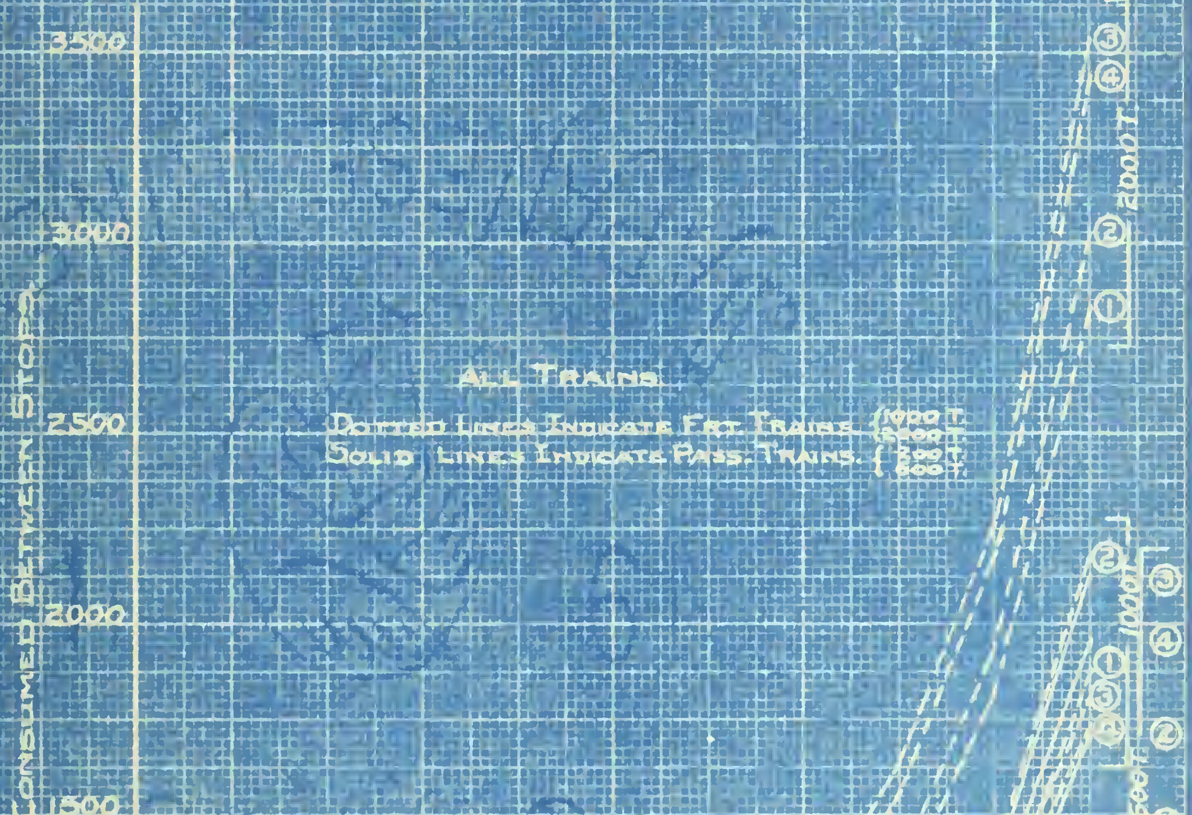
All Trains.
Dotted Lines Indicate Frt. Trains {1000 T / 2000 T
Solid Lines Indicate Pass. Trains. {200 T / 600 T
Pounds of Fuel Consumed Between Stops
3500
3000
2500
2000
1500
1000
500
0
B
C
D
E
F
G
H
I
J
K
Stations.
③
④
2000 T.
②
①
②
1000 T.
③
④
①
③
②
600 T.
②
①
④
②
200 T.
①
③

Fig. 12

From the values of time given in Table II, it seems advisable to use a small wheel locomotive for runs which do not exceed 3 miles in length when a 200 ton train is handled, as the time saved in the case of a 1550 horse-power locomotive varies from 6.5 to 0%, depending upon the length of run. If the length of run is one-half mile, then the per cent is large; if the run is three miles, then the per cent is very small. For runs greater than 3 miles, the large wheel locomotive at the head of a 200 ton train is a time-saver. The amount of time it can save as compared with the small wheel locomotive varies from zero when the length of run is three miles to 1.4% for runs sixteen miles in length. By reference to Figures 8 and 12, it is seen that the saving in the time consumed for short runs for the small wheel locomotive is off-set by a larger water and coal consumption, which probably would have continued had it not been for the conditions of the problem which limited the speed of the small wheel locomotive to 60 miles per hour, thereby enabling it to work at less than maximum power after having once attained its speed limit. Further discussion on the saving in water and fuel for locomotives when working below their maximum, is given in Appendix V. In the case of those runs which are greater than 3 miles in length, Figures 8 and 12 show very clearly the sacrifice made for time in the water and coal consumption for the large wheel locomotives when at the head of a 200 ton train.

For a train weight of 600 tons, it seems advisable, from the standpoint of time consumed, to use a small wheel locomotive for runs less than 6 miles in length, as a saving varying from 9.8 to 0% is effected, depending upon the length of the run. If the length of the run is small, then the time saved is relatively large, and conversely, if the length of run is great, the time saved is relatively small. For the distances under consideration, and for the 600 ton train, the water and coal consumption are practically the same (See the curves in Fig. 9). For runs greater than 6 miles and less than 16 miles in length, the saving in time for the large wheel locomotive at the head of a 600 ton train varies from 0 to 0.6%, depending on the length of the run. Also the saving in the water and fuel consumed for the large wheel locomotive under these conditions varies from 0 to 8.2% for the water and from 0 to 8.7% for the coal. From the analysis it appears quite evident that for runs greater than six miles in length, a large wheel locomotive of 1550 horse-power at the head of a 600 ton train is not only a time-saver but is more economical in the consumption of water and fuel than a small wheel locomotive.

For the 1000 and 2000 ton freight trains, the small wheel engine can show a saving of time over the large wheel engine of the same horse-power varying from 18.5 to 0.8% for all runs shown in the hypothetical profile (Fig. 6) for the local schedule. The longest run considered in this profile is

only 16 miles, which is not of sufficient length to justify a conclusion that for such trains hauled by a 1550 horse-power locomotive, the small wheel engine would always have the advantage over the large wheel engine as a time saver. In the case of the 1000 ton freight train, the water and coal consumption varies from 31.5 to 0% in favor of the large wheel locomotive for runs less than 5 miles in length. For runs of greater length, the small wheel locomotive soon reaches its maximum speed at less than maximum power, hence the saving in the water and coal consumption as shown by Figures 10 and 12. For the 2000 ton freight train, the small wheel locomotive is the more economical in water consumption, but must give way to the large locomotive as being more economical in coal consumption. (See Figures 11 and 12).

In general, if time is of first importance, then for short distances, as in suburban work, it seems that the small wheel locomotive is to be preferred. For longer runs, the large wheel locomotive is to be preferred provided the trains are not too heavy. For cases where the trains are heavy, the small wheel engine again has the advantage.

If an economy in the water and coal consumption is effected by using either small or large driver locomotive at the head of certain trains, then it becomes a matter of judgment as to whether it is best to sacrifice time to effect a saving in the water and fuel consumed.

THROUGH SCHEDULES.

As previously stated, it is proposed to have the four selected locomotives operate at the head of the four selected trains on a through schedule, and to determine the time, water and coal consumption for each of the locomotives at the head of each of the trains.

A hypothetical profile of the track is given in Fig. 7. It consists of a run 150 miles in length; the first 50 miles is on a 1% up grade; the second 50 miles is on level track; and the third 50 miles on a 1% down grade; with stops of no duration at the end of each 50 miles.

Calculations pertaining to time consumed were made in accordance with the method outlined in the second part of Appendix IV. These results have been tabulated as shown by Table IV, and plotted with respect to train weight for each locomotive as shown by Fig. 13. In this figure and in the several that are to follow, the numerals enclosed in the small circles refer to the number of the locomotive. In every instance Fig. 13 seems to display time curves which are in no way abnormal or irregular unless it be for locomotive No. 4 operating on level tangent track. In this case, it seems as though a 600 ton train is the heaviest that this locomotive should handle if time is a factor in the operation. For trains of greater weight, the time required for locomotive No. 4 to travel the same distance increases very rapidly, until the time is governed by the speed limit for such heavy trains. The characteristics of the locomotive are in part responsible for the peculiarity of this curve. (See Fig. 4).

TABLE IV-A.

(1% up grade).

For a portion of the through schedule run of 150 miles, of which the first 50 miles is on a 1% up grade, the second 50 miles on level track, and the third 50 miles on a 1% down grade.

Train Weights	Locomotive Numbers			
	1	2	3	4
TIME, minutes				
200 ton	100.64	86.0	75.45	75.53
600 "	*	200.27	150.37	151.06
1000 "	*	*	200.58	*
2000 "	*	*	*	*
WATER CONSUMPTION, pounds				
200 ton	31100	35105	43500	43166
600 "	*	82880	86912	86523
1000 "	*	*	115840	*
2000 "	*	*	*	*
COAL CONSUMPTION, pounds				
200 ton	5660	6390	7910	7850
600 "	*	15050	15780	15720
1000 "	*	*	21080	*
2000 "	*	*	*	*

* Beyond capacity of locomotive.

TABLE IV-B.

(Level track).

For a portion of the through schedule run of 150 miles, of which the first 50 miles is on a 1% up grade, the second 50 miles on level track, and the third 50 miles on a 1% down grade.

Train Weights	Locomotive Numbers			
	1	2	3	4
	TIME, minutes			
200 ton	51.45	51.0	50.65	43.93
600 "	76.75	68.10	61.40	48.77
1000 "	100.06	87.31	76.58	76.81
2000 "	153.50	122.10	101.91	102.55
	WATER CONSUMPTION, pounds			
200 ton	15900	18060	13935	24840
600 "	23650	28100	35335	27772
1000 "	30920	35604	31920	31345
2000 "	47430	50420	58667	58532
	COAL CONSUMPTION, pounds			
200 ton	2890	2955	1748	4520
600 "	4300	5120	6430	5050
1000 "	5620	6480	5800	4592
2000 "	8630	9180	10660	10650

TABLE IV-C.

(1% down grade).

For a portion of the through schedule run of 150 miles, of which the first 50 miles is on a 1% up grade, the second 50 miles on level track, and the third 50 miles on a 1% down grade.

Train Weights	Locomotive Numbers			
	1	2	3	4
		TIME, minutes		
200 ton	38.81	50.60	50.31	38.40
600 "	40.60	51.15	50.90	39.15
1000 "	76.0	76.53	75.50	75.91
2000 "	76.30	76.71	76.10	77.77
		WATER CONSUMPTION, pounds		
200 ton	*950	*531	*520	*920
600 "	*1810	*1138	*1223	*2140
1000 "	*642	*725	*810	*840
2000 "	*820	*960	*1160	*1203
		COAL CONSUMPTION, pounds		
200 ton	*172	*97	*95	*167
600 "	*329	*207	*223	*389
1000 "	*116	*132	*147	*152
2000 "	*149	*174	*211	*219

* Required during acceleration only, as the grade is sufficient to keep the train running at maximum speed.

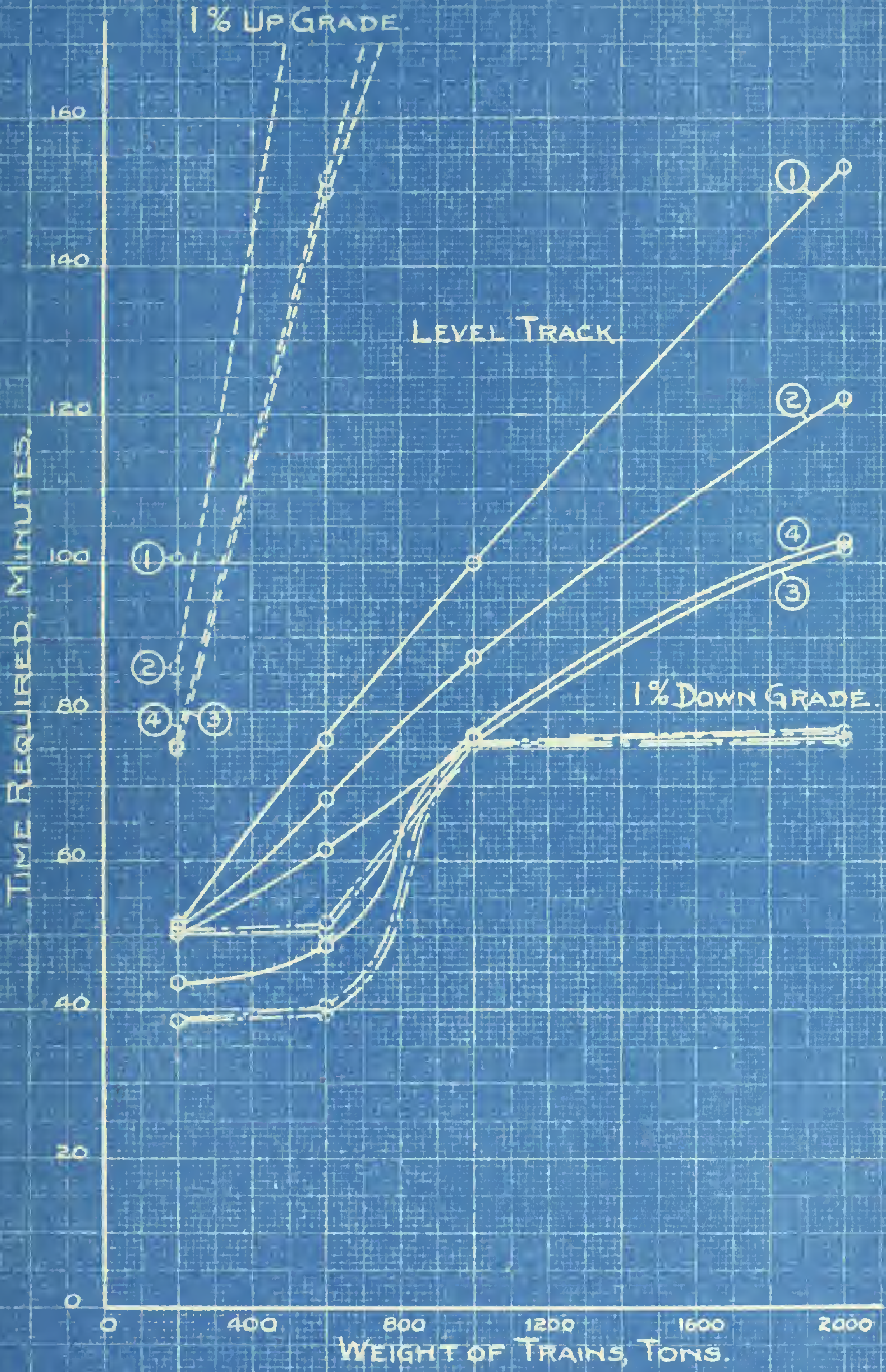

FIG. 13. TIME CONSUMPTION CURVES FOR A 50 MILE RUN.

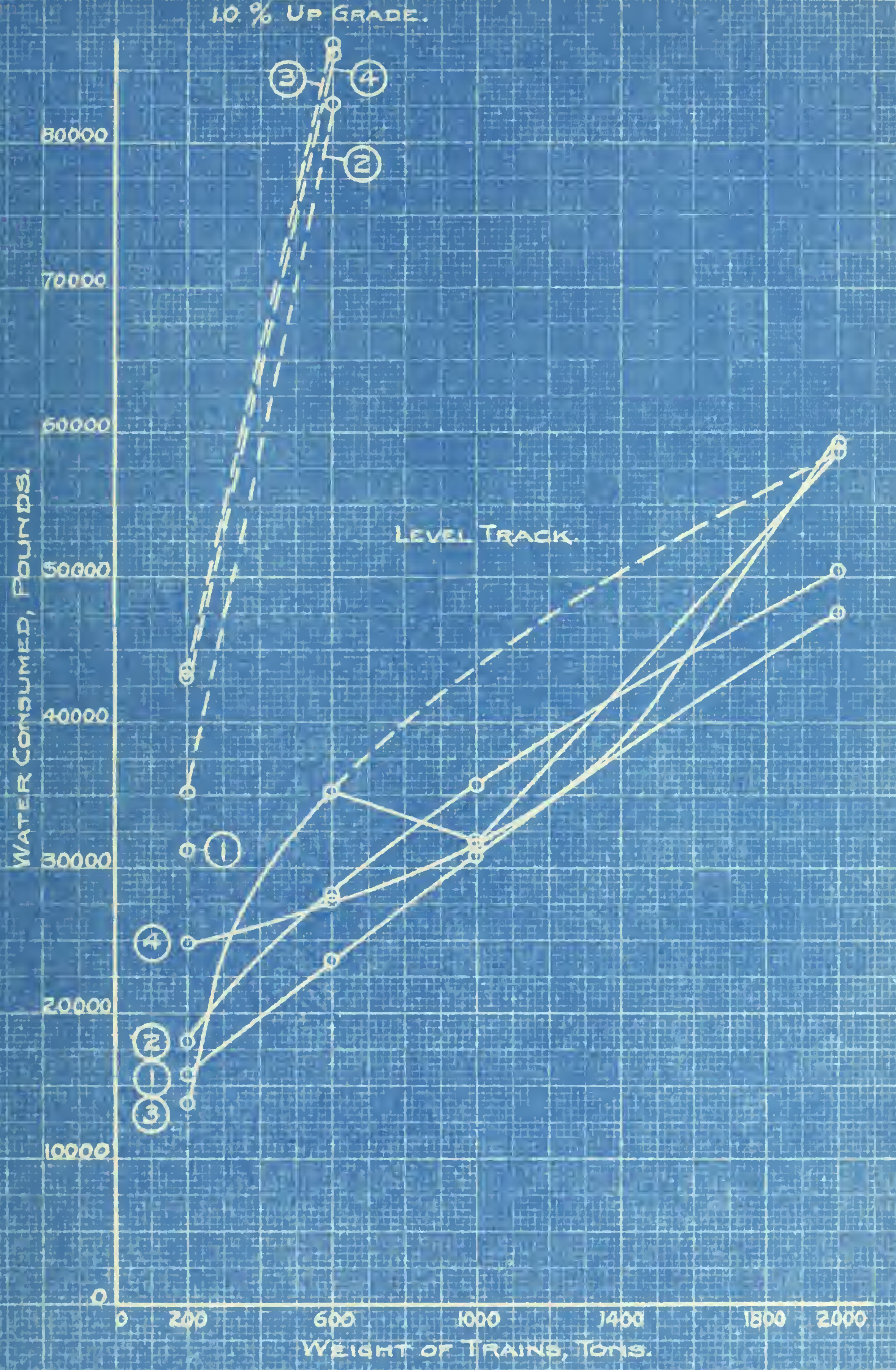

Fig. 14. Water Consumption Curves for a 30 Mile Run.

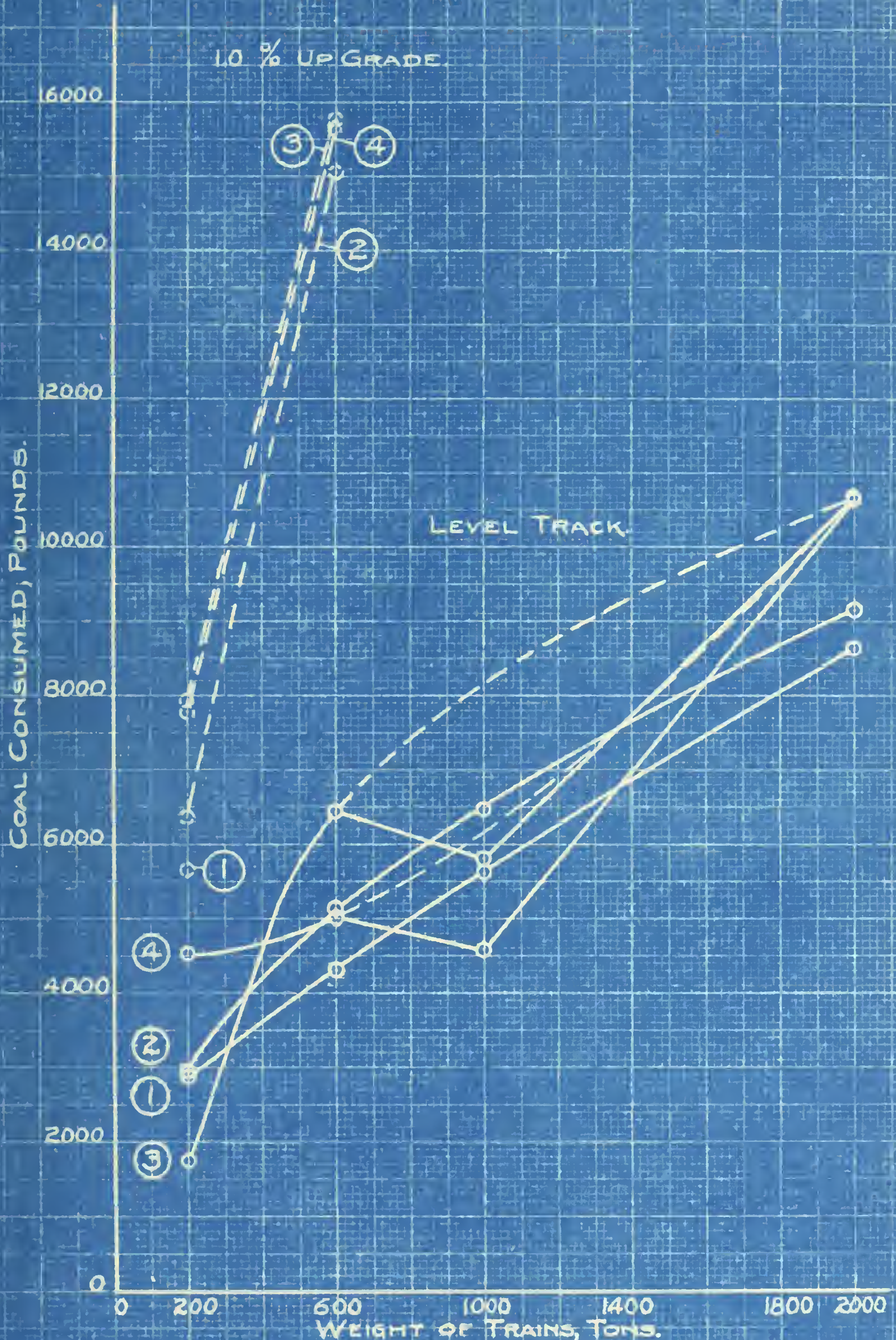

Fig. 15. Coal Consumption Curves for a 50 Mile Run.

Figures 14 and 15 show respectively the water and coal consumption for the four locomotives when operating at the head of the several trains, first on a 1% up grade, and second, on a level track. The curves for the run on a 1% down grade have been omitted, as they cannot be representative of good boiler performance due to so much drifting.

Attention is here called to the dotted sections of the curves (Figures 14 and 15) depicting water and coal consumption for the several locomotives at the head of different weight trains on level tangent track. In either figure the dotted sections represent what the consumption would have been if locomotives Nos. 3 and 4 had been permitted to travel at their maximum speed at the head of several heavy trains. For instance, if locomotive No. 3 had been permitted to attain its maximum speed when hauling the 1000 ton freight train, instead of being confined to a speed limit of 40 miles per hour as required by the conditions of the problem, it would have had a water consumption of 44000 pounds and a coal consumption of 8100 pounds for the 50 mile run. But with the speed limit imposed, the water and coal consumption is 32000 and 5800 pounds respectively.

In general, for the section of track 50 miles long and 1% up grade, less time is consumed by the small wheel locomotives of equal power, while the water and coal consumption for the 200 and 600 ton trains is slightly in favor of the

larger wheel locomotives. The heavier trains could not be handled on this grade, an exception being made in the case of locomotive No. 3 and the 1000 ton train, which were able to attain a speed of 15 miles an hour.

When on 50 miles of level track, the large wheel locomotives have the advantage in saving time when hauling light trains (200 to 600 tons) although the water and coal consumption suffers. For heavier trains (1000 to 2000 tons), the time required for equal powered locomotives is about the same, as is the water and coal consumption.

The time required on the 50 miles of down grade is less for the large wheel locomotives hauling light trains, while it is slightly in favor of the small wheel locomotives when hauling heavy trains. In the case of equal power locomotives, the large wheel locomotives have a greater coal and water consumption.

From these curves, it can also be shown that there is a decided saving in the water and fuel consumption in favor of the larger locomotive when two locomotives of unequal power are handling the same train, provided the difference in power is not excessive and that the smaller locomotive is operating at maximum power. This can be well shown by locomotives Nos. 2 and 3, which have the same size drivers but are of different horse-power, the former having a maximum rating of 1100 H.P., and the latter 1550 H. P. In Fig. 14, which shows the water consumption for the different locomotives operating at the head

of different weights of trains, it is apparent that the 1550 H. P. locomotive (No. 3) has a smaller water consumption than the 1100 H. P. locomotive (No. 2) when operating at the head of the 200 and 1000 ton trains. This is due to the fact that the smaller locomotive is working at a maximum all the time and the larger locomotive is working at possibly 5 to 10 miles per hour less than its maximum speed for a greater part of the time.

Under such conditions there arises the question whether it would not be more economical to buy locomotives slightly larger than necessary for a given service, so that they could have a normal maximum speed which would be possibly 5 to 10 miles per hour less than their rated maximum speed when operating at the head of a certain train. If we discount maintenance, we could balance the increase in the net cost of a larger locomotive against the saving in water and coal consumption for that locomotive when it is operated in the service for which it is designed. To the writer it seems that the preceding discussion assists in substantiating the theory that the large modern locomotive can handle large trains with a reduction in the cost per ton mile per unit of time.

In general, the conclusions justified by a study of the problem presented on page 5, are to the effect that a locomotive having large drivers and small cylinder volumes is especially adapted to high speed running where a sacrifice in the initial tractive effort can be made for a proportionately

larger tractive effort at high speeds; that this lack of starting tractive effort in high speed locomotives restricts its use for acceleration work when compared with the small driver locomotive, thereby making it inferior to the small driver locomotive for rapid suburban or local service; that rates of acceleration are in inverse proportion to the diameter of the drivers.

Thus on the basis of service performed, the small wheel locomotive is used for local schedules and large wheel locomotive for through schedules.

A greater economy in train operation is secured by hauling heavy trains.

As applied to the economics of railway location, the methods used in attacking this problem are more precise and more accurate than any that have come to the notice of the writer.

The analysis given above shows that the predetermination of steam train operation may be predicted with accuracy, thus making possible a more complete study of the variables entering into the proper location of a projected line, and also in relocating or changing grades on an existing line, and in changing schedules or tonnage rating for existing equipment.

APPENDIX I

PART I

STEAM LOCOMOTIVE

TRACTIVE EFFORT

STEAM LOCOMOTIVE TRACTIVE EFFORT.

The variation of engine draw-bar pull or tractive effort of steam locomotives depends on two things: first, the cylinder capacity, and second, the boiler capacity. The characteristics of the cylinder and boiler, and their dimensional relation to each other, are generally determined by the character of the service for which the locomotive is desired.

MAXIMUM TRACTIVE EFFORT AT LOW SPEEDS.

It is a common practice in the design of steam locomotives to proportion the working parts so that at starting they just fail to slip the drivers on a good rail, thereby making the adhesion the absolute limit of tractive effort. In such cases, the tractive effort is determined by the size of cylinder, steam pressure in the cylinder, etc., and not by the weight of the drivers upon the rail and the coefficient of static friction between the wheels and rail. This coefficient of static friction may be, with excellent condition of wheel and rail, as high as 30%; with good conditions and with the aid of sand, 25%; with good conditions without sand, 22%; while on a slippery or icy rail it may fall to 8 or 10%. If this value of the coefficient of static friction is $\underline{n}$, and the value of the driver weight upon the rail in pounds is $\underline{W_d}$, then the limit of the tractive force is $\underline{nW_d}$.

Opposing this force $\underline{nW_d}$, is the force created by the steam pressure in the cylinders, which is transmitted through the engine mechanism to the wheel tread where it produces a force termed the tractive effort.

By the term maximum tractive effort at low speeds, is meant that force at the engine draw-bar that a locomotive is capable of exerting while at the same time sustaining full boiler pressure. Maximum tractive effort can only result under the combined conditions of full boiler pressure, long cut-off, wide open throttle, and low speeds. The low speeds generally have an upper limit ranging from 5 to 10 miles per hour. This upper speed limit is dependent upon the ratio of boiler capacity to cylinder capacity, that is, the maximum tractive effort is applicable to a speed where the cylinders have a demand less than, or equal to, the boiler capacity. For relatively small cylinders, the speed may reach 9 or 10 miles per hour, for relatively large cylinders the speed may reach only 4 or 5 miles per hour.

Maximum tractive effort for two cylinder simple locomotives may be derived in the following manner:

Let T.E. = maximum tractive effort in pounds, available at engine draw-bar on level track,

(m.e.p.)= maximum mean effective pressure in pounds per square inch,

d = diameter of cylinder in inches,

D = diameter of driving wheels in inches,

and s = stroke in inches.

Then assuming no losses between the cylinders and engine draw-bar, the work done in both places is the same, or the work done at the cylinders is equal to the work done at the engine draw-bar. Now, while a driver of diameter *D* makes one revolution, both pistons make four strokes, each of length *s*, due to the action of a mean effective pressure (m.e.p.). The work done at the cylinders is $4((\text{m.e.p.})\frac{\pi}{4}d^2s)$ inch pounds; the work done at the engine draw-bar is $\pi D(\text{T.E.})$ inch pounds. Equating these expressions, we have,

$$\pi D(\text{T.E.}) = (\text{m.e.p.})\pi d^2 s$$

or

$$\text{T.E.} = \frac{(\text{m.e.p.})d^2 s}{D} \qquad (1)$$

From the results of tests at low speeds, the maximum mean effective pressure (m.e.p.) is found to be about 92.5 per cent of the boiler pressure, when the engine is working under maximum cut-off. In some cases the mean effective pressure has reached the extreme limit of 94 per cent of the boiler pressure. When operating under such conditions, the maximum machine efficiency is about 92 per cent. Therefore equation *1* may be revised by substituting the boiler pressure *P*, in pounds per square inch, in place of the term *m.e.p.*, as

$$\text{T.E.} = \frac{0.925 \times 0.92 \times Pd^2 s}{D}$$

$$= \frac{0.85\ Pd^2 s}{D} \qquad (2)$$

Formula 2 is used to determine tractive effort at low speeds unless it gives results that are greater than one-fourth the weight on drivers, in which case the latter value of 1/4 W_d is used.

MAXIMUM TRACTIVE EFFORT AT HIGH SPEEDS.

In the preceding discussion of tractive effort at low speeds, there is assumed to be ample boiler capacity for supplying steam, but as the speed increases, the cylinders demand more steam per unit of time until the cut-off must be shortened in order to maintain boiler pressure. Evidently the capacity of the boiler has been reached and is the limiting feature in tractive effort at high speeds.

Methods for the determination of maximum tractive effort for simple locomotives at high speeds have been proposed by many experimentors, chief among whom is Dr. W.F.M. Goss, who proposed the following formula:

$$T.E. = \frac{161\ H}{V} \qquad (3)$$

where T.E. = tractive effort in pounds on level track,
H = heating surface in square feet,
and V = velocity in miles per hour.

In equation 3 it is assumed that any locomotive boiler can develop an actual evaporation rate of 12 pounds of water for each square foot of heating surface per hour, and that 28 pounds of steam are required per I.H.P.H. In the tests from which these results are taken, the boiler had a

grate area of 17.25 square feet, and a ratio of heating surface to grate surface equal to about 70. The thermal value of the coal was about 13000 B.T.U. per pound.

In the formation of equation 3 there are three points to which the writer wishes to call attention and, in a way, to make corrections for them in the development of a new equation for tractive effort at high speeds. These points are:

1. The assumption that a fireman always possesses the strength and ability to fire any locomotive boiler at the rate of 12 pounds of actual evaporation per square foot of heating surface per hour.
2. The assumption that the thermal value of the coal fired is always the same.
3. The assumption that at all speeds the steam consumption per I.H.P.H. is constant.

In other words, it is the intention of the writer to develop a formula for tractive effort at high speeds, and instead of basing such a formula on the heating surface only, it will be based on the performance of the fireman, the heating surface, the rate of evaporation, and the steam consumption per I.H.P.H. as variables. Points 2 and 3 above were discussed in the Railway Age Gazette for March 22, 1912, and the results given were based on long periods of sustained operation, which seem unreasonable for typical American practice where the average profile of the railroads is rolling, requiring sustained operation for short periods only. For this reason, the following table

is inserted to exhibit the results of the tests of different steam locomotives, from which data has been taken to form the basis of the steam consumption curves given in Fig. 16, page 51.

TABLE V.

STEAM CONSUMPTION OF LOCOMOTIVES. (Full throttle)

Simple Freight Locomotives.

No.	Type	Drivers	R.P.M.	C.O.	I.H.P.	Steam per I.H.P.H.
1499	2-8-0	56"	40	22.4	366	* 28.33
			40	30.5	455	* 27.29
P.R.R.			80	22.8	650	25.51
			80	20.9	588	25.31
Tested at			80	29.2	779	* 23.92
			80	39.3	931	* 24.70
St. Louis, Mo.			120	31.3	975	* 23.43
			120	34.0	1036	* 23.74
in 1904.			160	22.2	803	* 24.78
			160	28.0	951	* 23.73
734	2-8-0	63"	40	19.2	299	29.56
			40	30.7	434	* 27.78
L.S.& M.S. RR.			40	41.3	550	* 27.31
			80	17.3	527	25.89
Tested at			80	30.7	782	* 24.55
			80	40.7	963	* 24.93
St. Louis, Mo.			160	21.1	865	25.11
			160	23.3	954	* 24.67
in 1904.			160	27.4	1054	* 23.92

Compound Freight Locomotives.

585	2-8-0	63"	40	43.1	443	20.20
			40	45.3	477	* 20.09
M.C. RR.			40	48.6	512	* 20.27
			80	42.2	735	20.15
Tested at St. Louis, Mo.			80	45.7	841	* 19.54
			80	52.8	932	* 19.70
in 1904.			80	57.5	1041	* 20.03
			160	49.6	890	* 23.18
			160	50.7	992	* 22.80

* These points have been plotted in Figure 16.

TABLE V. (continued)

STEAM CONSUMPTION OF LOCOMOTIVES. (Full throttle)

Compound Passenger Locomotives.

No.	Type	Drivers	R.P.M.	C.O.	I.H.P.	Steam per I.H.P.H.
535	4-4-2	79"	80	26.7	356	23.67
			80	31.0	479	21.67
A.T.& S.F.			80	37.6	570	21.91
			80	53.0	808	* 20.56
Tested at			160	36.1	877	19.44
			160	43.0	1000	* 20.17
St. Louis, Mo.			160	50.5	1296	* 19.41
			240	46.4	1414	19.99
in 1904.			240	51.3	1622	* 20.48
			240	52.9	1549	* 20.82
			280	47.7	1460	* 20.73
3000	4-4-2	79"	80	36.0	567	* 20.78
			80	45.9	714	* 20.47
N.Y.C.& H.R.RR.			160	36.3	967	19.60
			160	43.7	1253	* 19.95
Tested at			160	57.1	1491	* 21.57
			240	32.2	1143	21.05
St. Louis, Mo.			240	46.6	1630	* 22.18
			240	53.7	1641	* 24.14
in 1904.			280	32.2	1192	* 22.27
			280	38.2	1369	* 22.19
			320	41.0	1336	* 23.51
2512	4-4-2	80"	80	27/52	310	21.20
			80	39/60	496	18.60
P.R.R.			160	25/52	525	19.95
			160	27/53	525	21.15
Tested at			160	38/60	809	19.60
			160	50/70	945	20.67
St. Louis, Mo.			240	28/50	597	21.95
			240	30/57	653	22.69
in 1904.			240	34/62	802	21.62
			280	29/58	683	27.05

---

* These points have been plotted in Figure 16.

TABLE V. (continued)

STEAM CONSUMPTION OF LOCOMOTIVES. (Full throttle)

Simple Passenger Locomotives.

No.	Type	Drivers	R.P.M.	C.O.	I.H.P.	Steam per I.H.P.H.
5266	4-4-2	80"	80	15.7	420	33.54
	E 2 A		80	17.9	477	32.27
			80	23.7	585	* 30.65
P. R.R.			80	29.7	728	* 29.94
			120	18.8	688	28.81
Tested at			120	24.9	851	* 26.70
			120	31.7	1015	* 26.63
Altoona, Pa.			160	16.7	749	26.75
			160	20.2	827	25.34
in 1909.			160	24.9	1012	* 25.23
			160	27.7	1055	* 26.50
			160	31.5	1133	* 26.46
			200	19.5	1019	* 24.83
			200	25.5	1224	* 23.84
			240	19.0	1085	* 24.60
			240	21.60	1165	* 24.37
			280	19.9	1178	* 23.81
			320	21.4	1281	-
Purdue	4-4-0	63"	108	27.0	376	* 26.01
Loco.			108	34.0	473	* 26.31
			162	27.0	489	* 24.91
			215	27.0	605	* 24.43
Tested at						
Lafayette, Ind.						

* These points have been plotted in Figure 16.

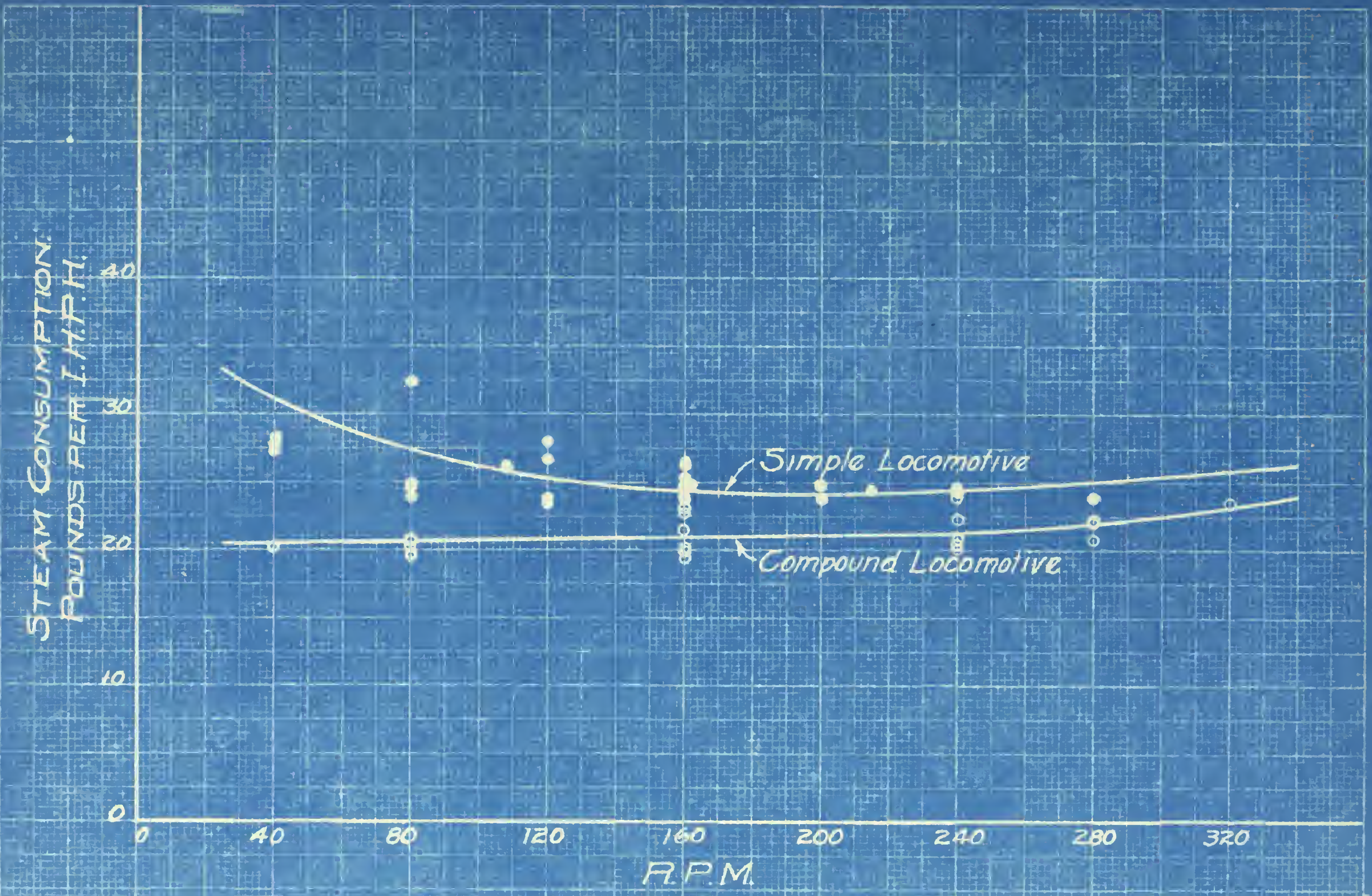

FIG. 16. STEAM CONSUMPTION PER I.H.P.H.

The asterisk in the above table indicates that those values have been plotted in Fig. 16 and are considered as representative points for probable water rates when the locomotive is working at maximum power for the different speeds.

Owing to the fact that the tests at low speeds are made with considerably less than maximum power, the steam consumption curve for simple locomotives has not been drawn through the plotted points, as an attempt has been made to have it representative of maximum working conditions.

The water rate for simple locomotives as shown in Fig. 16 may be represented by an empirical equation,

$$S = 34.0 - 0.1 R + 0.001\frac{R^2}{4}$$

where

S = pounds of steam consumed per I.H.P.H.

and R = revolutions per minute.

For compound locomotives there is not the variation in the water rate as in the case of simple locomotives, as is shown by the curve in Fig. 16. It would seem that a constant water rate of 21 pounds could be used as representing the average value, without introducing any material error.

From an analysis of the results of locomotive tests performed at St. Louis, Missouri, Lafayette, Indiana, and at Altoona, Pennsylvania, the following table is submitted:

TABLE VI.

B.T.U. per pound of coal.	Fair value of a maximum rate of equivalent evaporation for any locomotive.
15000	13.00
14000	12.20
13000 - - - - - - - - - -	11.50
12000	10.90
11000	10.35
10000	9.90

These rates of maximum evaporation may be expected from any locomotive boiler working to a maximum, under ordinary conditions of the road, with a normal ratio of heating surface to grate surface, and economic firing. It is here assumed that the required rate of firing the fuel is within the limits of the fireman's strength. This table is based on a maximum rate of equivalent evaporation of 12.89 pounds per square foot of heating surface per hour, for a locomotive having 2700 square feet of heating surface, with ratio of heating surface to grate surface equal to 61, thereby requiring 4730 pounds of coal having a thermal value of 14850 B.T.U. to be fired per hour.

The power developed by a boiler is proportional to the rate of evaporation, the rate of evaporation is dependent on the proportions of the boiler and the amount of fuel which the fireman can handle economically. If a coal of high

thermal value is used to increase the evaporative efficiency of the boiler, thereby making it possible to evaporate more water for each pound of fuel consumed, then the boiler may be forced to its maximum power. Of course, if this causes a firing rate too high for the fireman, and it is desirable to retain this maximum evaporative efficiency, then it becomes necessary to resort to some method of mechanical stoking.

With the modern locomotive where the heating surface is very large, and with a normal ratio of heating surface to grate surface, it is impossible for the average fireman to hand-fire such a locomotive up to the maximum rate of evaporation, especially is this so if the fuel is not of high thermal value. In such a case the limit on the output of power is found not in the proportions of the locomotive, but in the strength and ability of the fireman.

DERIVATION OF FORMULA FOR MAXIMUM TRACTIVE EFFORT.

It is evident that the work developed in the cylinders of a locomotive is equal to the work available at the draw-bar, provided that there are no frictional losses between these points. Then this may be represented thus:

$$\text{WORK (in the cylinders)} = \text{WORK (at the draw-bar)}$$

or

$$\begin{aligned} \text{I.H.P.} \times 33000 \times 60 &= \text{D.B.P.} \times \text{distance traversed in feet per hour,} \\ &= \text{D.B.P.} \times 5280 \times \text{velocity (V) in miles per hour,} \end{aligned}$$

or $$\text{D.B.P.} = \text{T.E.} = \frac{\text{I.H.P.} \times 33000 \times 60}{V \times 5280}$$

$$= \frac{375 \times \text{I.H.P.}}{V} \qquad (4)$$

Now, if

E = maximum rate of equivalent evaporation per square foot of heating surface per hour,

e = maximum rate of actual evaporation per square foot of heating surface per hour,

S = actual steam consumption per I.H.P.H., pounds,

and H = number of square feet of heating surface, (fire side). (For superheater engines let one square foot of superheating surface be equivalent to one and one-half square feet of water heating surface).

then

$$\text{H.P.} = \frac{e \times H}{S}$$

Since the evaporation rate is generally given in terms of equivalent evaporation from and at 212° F., it seems advisable to put e in terms of E. This may be done in the following manner; if we assume a boiler gauge pressure of 200 pounds per square inch and a feed water temperature of 60° F.

Let F equal the factor of evaporation, then

$$e = E \times \frac{1}{F}$$

Now, F = 1.2069 for a feed water temperature of 60° F., and 215 pounds absolute pressure. Therefore, for average conditions

$$e = E/F = \frac{E}{1.2069}.$$

By substitution

$$\text{H.P.} = \frac{E \times H}{1.2069S} \qquad (5)$$

Substituting the value for horse-power in equation 5 into equation 4, we have

$$\text{T.E.} = \frac{310.7 \times E \times H}{V \times S} \qquad (6)$$

Formula 6, which is a general formula for steam locomotive tractive effort, will serve as a basis for all calculations pertaining to locomotive tractive effort as treated in this article.

For convenience in applying this formula, the approximate relations existing between the revolutions per minute of the drivers and the speed in miles per hour of the locomotive, for different diameters of drivers, is shown in the following table:

TABLE VII.

R.P.M. at 10 m.p.h.

Wheel Diameters	56"	57"	58"	59"	60"	61"
R. P. M.	60.0	59.0	57.9	57.0	56.0	55.1
Wheel Diameters	62"	63"	64"	65"	66"	67"
R. P. M.	54.2	53.4	52.5	51.7	50.9	50.2
Wheel Diameters	68"	69"	70"	71"	72"	73"
R. P. M.	49.4	48.7	48.0	47.3	46.7	46.0
Wheel Diameters	74"	75"	76"	77"	78"	79"
R. P. M.	45.4	44.8	44.2	43.7	43.1	42.6

TABLE VII (continued)

Wheel Diameters	80"	81"	82"	83"	84"	85"	86"
R. P. M.	42.0	41.5	41.0	40.5	40.0	39.6	39.1

On the same basis on which Table VI is estimated, the following table is presented, showing different areas of heating surface which, under maximum rates of evaporation when fuel of any thermal value is used, require the accompanying pounds of coal that must be fired economically:

TABLE VIII.

When heating surface is equal to:	Pounds of coal that must be fired per hour.
2700 square feet	4730
3000 " "	5260
3500 " "	6120
4000 " "	7000
4500 " "	7880
5000 " "	8760
5500 " "	9640
6000 " "	10520

When B.T.U. value of coal = 14850 and rate of equivalent evaporation = 12.89 lb., or, when any other pair of values given in Table VI are used.

For example, suppose a locomotive has 3500 square feet of heating surface, 80 inch driving wheels, and is to be fired with a coal having a thermal value of 13000 B.T.U. per pound.

To find its tractive effort at high speeds; first, by Table VI it is found that a fair value for the maximum rate of equivalent evaporation per square foot of heating surface per hour is 11.5 pounds. And in Table VIII it is found that 6120 pounds of coal must be fired per hour. If the fireman can fire at this rate, then it is simply a question of substituting into equation 6 the following values:

$$E = 11.5$$

$$H = 3500$$

$$S = 34.0 - 0.1\,R + 0.001\frac{R^2}{4}$$

If a coal of different thermal value is used, then the value of E will change correspondingly.

Now, if we again take the above example, and limit it to the fireman's performance by saying that a certain fireman can only fire 5000 pounds of coal per hour, then 6120-5000 or 1120 pounds of coal are not fired in each hour. In such a case, we cannot expect 11.5 pounds as a maximum value of E. But, if we take 5000/6120 of 13000, we obtain the thermal value of an equivalent coal, which gives the same rate of evaporation corresponding to the thermal value given in Table VI as that portion of the original coal which is actually fired. This correction is necessarily due to the

inability
incapacity of the fireman to handle the entire weight of coal given in Table VIII. Now, 5000/6120 x 13000 = 10620, which is the thermal value of this equivalent coal. Then by interpolation in Table VI, the maximum rate of evaporation is 10.18 pounds.

To find the tractive effort of this locomotive when limited by the performance of the fireman, it is only necessary to substitute in equation 6 the following values:

$$E = 10.18$$

$$H = 3500$$

$$S = 34.0 - 0.1R + 0.001\frac{R^2}{4}$$

Dr. W.F.M.Goss, in his "Locomotive Performance", arrives at similar conclusions when he expresses cylinder horse-power in terms of heating curface. The results of his tests at Purdue University justified him in using 28 pounds of steam per I.H.P.H., and an actual evaporation rate of 12 pounds of steam per square foot of heating surface per hour. Then as many horse-power are delivered per square foot of heating surface as are expressed by the ratio of 12/28 or 0.43, that is:

$$I.H.P. = 12.28 \times H.S. = .43\ H$$

and as previously shown,

$$T.E. = 375\ \frac{I.H.P.}{V}$$

By substitution,

$$\text{T.E.} = \frac{375 \times 0.43\ H}{V}$$

$$= \frac{161 \times H}{V} \qquad (7)$$

This formula gives values which are about 11.2 per cent higher than those which are obtained by the use of formula 6. The proof of this statement is based on the assumption that 25 pounds per I.H.P.H. steam consumption is sufficiently accurate to be taken as constant (See Fig. 16), and that the steam which is generated is subject to the requirements of the cylinders only, as the air pump and safety valve generally make their demand on the boiler when the cylinders are not working. The water rate for the average locomotive using saturated steam is from 22 to 30 pounds per I.H.P.H., and for superheater locomotives this amount may be safely reduced 18 per cent.

In the tests made at Purdue University and published in "Locomotive Performance" by Dr. Goss, a coal was used which had an average thermal value of 13000 B.T.U. per pound. Therefore, a reduction of formula 6 to the terms found in formula 7 for purposes of comparison, necessitates the following substitutions, viz:

Thermal value of dry coal = 13000 B. T. U.,
Steam consumption = 25 pounds per I.H.P.H.,
and Rate of evaporation = 11.5 pounds.
(On the assumption that the performance of the fireman is unlimited).

By substitution in formula 6, we have

$$\text{T.E.} = \frac{310.7 \times 11.5 \times H}{25 \times V} = \frac{143\ H}{V} \qquad (8)$$

The ratio of 161 in equation 7 to 143 in equation 8 gives the proportional increase in values to be expected, which is 11.2 per cent, when equation 7 is used to determine the variation of locomotive tractive effort with velocity. When other coals whose thermal values are lower than 13000 B.T.U. are burned in the locomotive fire-box, the difference in values of tractive effort, when solved by equation 7, will continue to increase in proportion to the changes in the rates of equivalent evaporation. If coals of better thermal values than 13000 B.T.U. per pound are fired, then the difference in values of tractive effort, when solved by equation 6 and then by equation 7, will continue to decrease, and the resulting values from either formula will become equal to one another when a coal of 14950 B.T.U. per pound thermal value is fired.

Therefore, it seems that the use of formula 6 which has a valid derivation and gives more reasonable and more accurate results of locomotive tractive effort at the cylinders than other formulae where the size and speed of the driving wheels, the thermal value of the coal, and the performance of the fireman are neglected, is justified.

APPENDIX I

PART II

CALCULATIONS OF STEAM LOCOMOTIVE TRACTIVE EFFORT.

CALCULATIONS OF STEAM LOCOMOTIVE TRACTIVE EFFORT.

The discussion in Appendix I, Part I, indicates that at slow speeds where there is no question as to the ability of the boiler to supply steam at boiler pressure with full cut-off, that the equation

$$T.E. = \frac{0.85\ Pd^2s}{D} \text{ (for low speeds)}$$

for determining tractive effort at the cylinders will produce reliable values which can be depended upon in service. At higher speeds the boiler is required to furnish more steam per unit of time until it reaches its maximum evaporative power, at which time the rate of steam generation is constant and the boiler becomes the limiting factor in tractive effort.

The determination of tractive effort at high speeds or when the boiler is working to its full capacity is more or less inexact. The variables which enter into its determination are many, and when several of them are acting at once, it is practically impossible to anticipate the characteristics of any particular locomotive.

A formula for tractive effort at high speeds in pounds of draw-bar pull equivalent to the power developed in the cylinders, assuming no transmission losses, has been developed by the writer, and is shown as equation 6 in Appendix I, Part I, which is:

$$T.E. = \frac{310.7 \times E \times H}{V \times S} \quad \text{(for high speeds)}$$

For the purposes of this discussion and for comparison, ideal conditions have been assumed for the various factors affecting locomotive tractive effort. The assumptions will include like ratios of locomotive boiler and cylinder proportions, similar valve gears, like methods of firing, and firemen of equal skill. For instance, throughout this article it is assumed that the fireman will fire will skill and efficiency and can fire at the rate of 6500 pounds of coal per hour for a period of thirty minutes; that the grade of coal has a thermal value of 13000 B.T.U. per pound, which is probably better than the average coal used by most railroads.

In this problem and for most cases dealing with tractive effort, it is preferable to deal with it in terms of tender draw-bar pull, or, in other words, it is desirable to know the available draw-bar stress which can be utilized for pulling trains. To arrive at a value for this tender draw-bar stress, it is necessary to deduct for the various losses occurring between the cylinders and the tender draw-bar. These losses may be classified thus:

1. Machine friction of the engine, which includes the rolling resistance of the drivers.
2. Rolling resistance of the leading and trailing trucks.
3. Rolling resistance of the tender.

4. Resistance which the atmosphere offers to the head end of a train.

5. The resistance due to grade.

The subject of machine friction has been discussed in Appendix II, in which the equation

$$R_1 = 22.0\ W_d$$

is suggested as representing the loss in pounds of draw-bar stress due to the machine friction and rolling resistance of the drivers for any non-articulated locomotive. For articulated locomotives the constant 22.0 is generally replaced by 30.0, although the data on the subject is too meagre to verify any reliable conclusion.

The rolling resistance due to the engine trucks is assumed to be the same as for an equal weight of train following the tender. The expression representing this variation is given by equation 13 in Appendix III. The expression is:

$$R_2 = \frac{V + 41}{.684\frac{W}{A} + 3.8}$$

Similarly, the rolling resistance of the tender is assumed to be the same as for an equal weight of train. The expression representing this variation is given by equation 25 in Appendix III. The expression is:

$$R_3 = \frac{V + 41}{.12\ W_m + 3.8}$$

The resistance offered by the atmosphere to the movement of an engine at the head of a train is represented by equation 24 in Appendix III, which is:

$$R_4 = \frac{V^2}{3}$$

The resistance due to grades is represented by equations 29 and 30 in Appendix III, which are:

$$R_5 = 20 (W_1 + W_t) G$$

or, $$R_5 = 0.379 (W_1 + W_t) g$$

In all the above equations, the characters employed signify the following:

R_1 = resistance in pounds of draw-bar stress equivalent to the machine friction;

R_2 = resistance in pounds of draw-bar stress equivalent to the rolling resistance of the engine trucks;

R_3 = resistance in pounds of draw-bar stress equivalent to the rolling resistance of an average loaded tender;

R_4 = resistance in pounds of draw-bar stress equivalent to the resistance offered by the atmosphere;

R_5 = resistance in pounds of draw-bar stress due to grades;

E = equivalent evaporation per square foot of heating surface per hour;

H = square feet of heating surface in boiler;

S = actual pounds of steam per I.H.P.H.;

P = boiler pressure in pounds per square inch;

d = diameter of cylinder in inches;

s = length of stroke in inches;

D = diameter of driving wheels in inches;

W_d = weight on drivers in tons;

V = train speed in miles per hour;

W = total load in tons;

A = number of axles carrying the load W;

W_m = maximum weight of tender in tons (light weight plus full capacity);

W_l = weight of locomotive in tons;

W_t = weight of tender in tons;

G = the grade in per cent;

g = the grade in feet per mile.

Evidently the net tender draw-bar stress for any locomotive is:

$$T.E.(net) = T.E.(at\ cylinder) - R_1 - R_2 - R_3 - R_4 \pm R_5 \quad (9)$$

The sign of R_5 is positive (+) for down grades and negative (-) for up grades.

This equation is general in its application.

On page 7 a table is given of the principal dimensions of four typical steam locomotives. To these locomotives formula 9 has been applied, which resulted in values of the forces actually developed at the tender draw-bar. If the results are put into tabular form, we have the following:

TABLE IX.

TENDER DRAW-BAR PULL, POUNDS.

Speed	Locomotive Numbers			
M.P.H.	1	2	3	4
5	15100	38450	42110	25600
10	15050	28650	40485	25540
15	13560	20250	29360	24460
20	11160	15450	22070	21650
25	9000	12350	17660	17530
30	7430	10050	14680	14810
35	6275	8150	12000	12490
40	5170	6700	10090	10600
45	4360	5350	8230	9020
50	3475	4250	6740	7520
55	2775	3250	5480	6390
60	2070	2350	4300	5290
65	1420	-	-	4220
70	800	-	-	3280
75	300	-	-	2590
80	-	-	-	1600

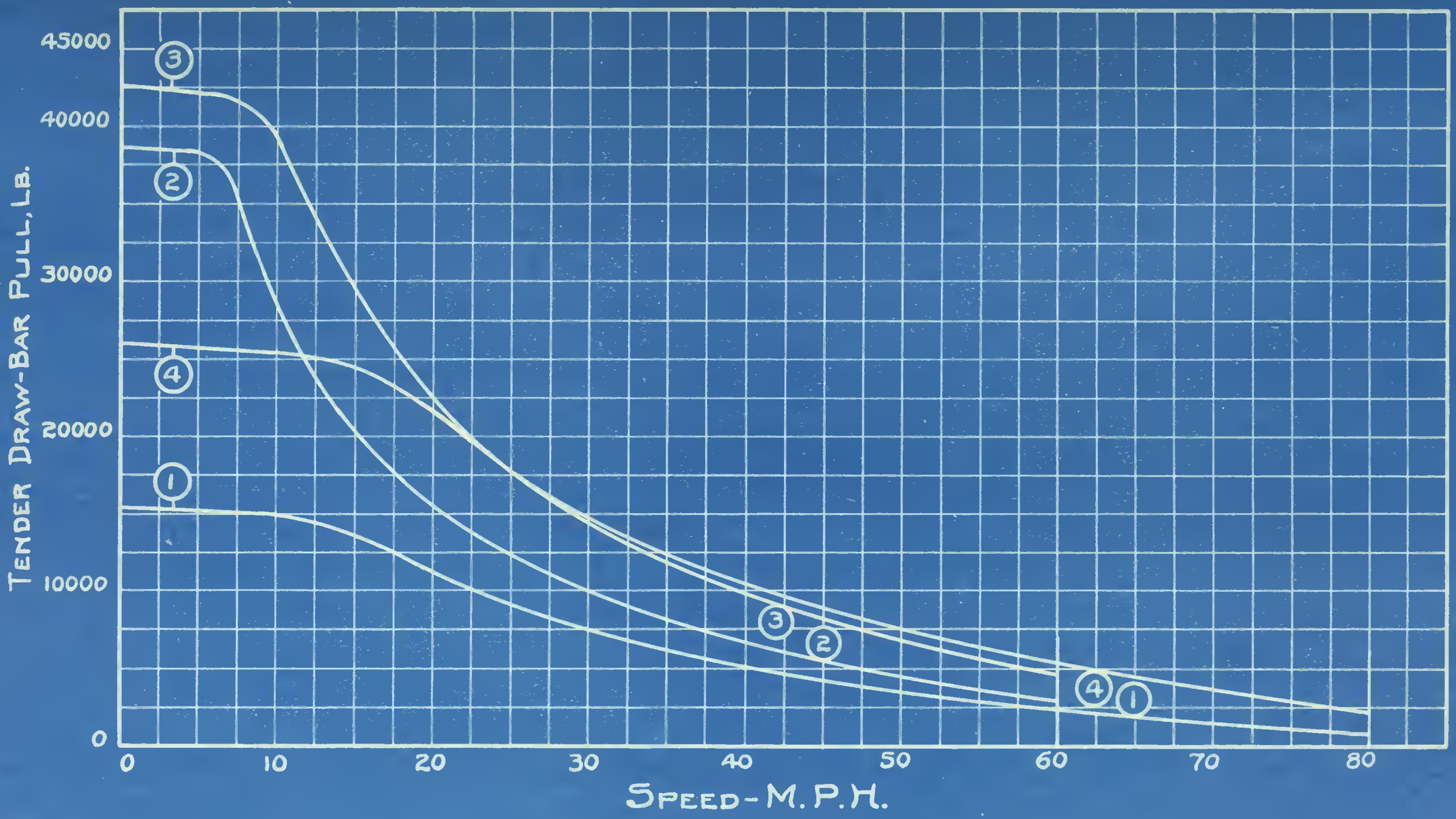

Fig. 17. Tractive Effort Curves.

The values given in the above table when plotted with respect to speed, as in the diagram shown by Fig. 17, apply only to the locomotives under consideration, and represent the maximum tractive efforts available at the tender draw-bar when the locomotives are running on level tangent track. When the track is not level, then the necessary correction must be made. This may be done by the use of the last term in equation 9.

In the case of locomotives No. 3 and No. 4 which are of equal power, the effect of different sized drivers is quite noticeable. For instance, locomotive No. 3 with its small wheels and large weight on drivers, gives very high tractive effort at low speeds, while locomotive No. 4 with its large drivers and less adhesive weight gives only about 60% of the tractive effort of locomotive No. 3 at low speeds. But at a speed of approximately 25 miles per hour, the tractive effort of the two locomotives is the same. At speeds greater than 25 miles per hour, the increment of decrease in tractive effort for Locomotive No. 3 is greater than for Locomotive No. 4. The small wheel locomotive is able to develop its maximum cylinder power up to a speed of 7.09 miles per hour, while the large wheel locomotive can reach a speed of 12.4 miles per hour and still develop maximum cylinder power.

APPENDIX II

MACHINE FRICTION
OF
STEAM LOCOMOTIVES.

MACHINE FRICTION
OF
STEAM LOCOMOTIVES.

The efficiency rating of steam locomotives is generally based on the indicated horse-power developed in the cylinders. In order to make possible a determination of the machine efficiency of the steam locomotive, some method is necessary for measuring the power developed in the cylinders and the power delivered at the draw-bar. Indicator cards from the cylinders form a basis for calculating the power developed in them, and to determine the power delivered, either a locomotive testing plant containing a dynamometer and its necessary adjuncts, or a dynamometer car so equipped that accurate measurements during the road test are obtainable, is required.

Machine friction (sometimes called engine friction) of steam locomotives, is measured as the power absorbed by the frictional resistances of the working parts of the engine. The determination of this friction, in locomotive testing plants, involves simultaneous observations at the cylinders and engine draw-bar; and it is the difference of the power indicated at these points which gives the power absorbed by machine friction consumed in the working parts of the mechanism.

If represented by a formula, we have:

(Indicated Cylinder power) - (Delivered power at draw-bar) = (Power absorbed by the machine).

And

$$\frac{\text{Delivered Power}}{\text{Indicated Cylinder Power}} \times 100 = \text{Machine efficiency in per cent.} \qquad (10)$$

Tests to determine machine friction of locomotives in road service are similarly made, the only exception which need be considered is to subtract the friction due to truck and tender resistance and to correct for grade. Of course, engine efficiency tests made on a track which is not level must be corrected for grade resistance in order that the results may be comparable with others and a true interpretation made as to what constitutes locomotive machine efficiency. Here it must be borne in mind that locomotive efficiency can vary between the limits of 0 and 85% or 90%, depending on the speed and draw-bar pull. In other words, the efficiency varies with the draw-bar pull, speed, and cut-off, and it is not possible to assign a definite value for the efficiency unless these conditions be fixed. For example, a locomotive and tender running light and at maximum speed, exert no available draw-bar pull, and the efficiency is therefore zero. In order to prevent ambiguity when the term efficiency is used, it is understood that the term general maximum efficiency is implied.

Machine friction may be expressed in terms of mean effective pressure, and for simple engines the usual tractive

effort equation gives a value of draw-bar pull which is the equivalent of machine friction when the force exerted by the cylinders is just sufficient to produce motion of the drivers with zero load at the engine draw-bar, as

$$D.B.P. = \frac{P\ d^2 S}{D}$$

where D.B.P. represents the equivalent pull due to machine friction, P represents the frictional mean effective pressure, d represents the diameter of the cylinder in inches, S represents the stroke in inches, and D represents the diamater of the drivers in inches.

This friction of steam locomotives may consume from 10 to 20 per cent of the indicated horse-power, depending upon the kind and method of lubrication and the condition of the mechanism.

To show a comparison between the actual machine friction as developed during tests and the machine friction as derived by formulae, Table 10 is inserted:

Columns Nos. 1 to 7 are self-explanatory.

Column No. 8 is the calculated machine friction expressed in pounds of draw-bar pull, determined by the formula recommended by the American Railway Engineering Association as expressing the relation existing between the friction of the moving parts, the weight on drivers, and the number of axles of steam locomotives. The formula is:

$$R = 18.7\ W_d + 80\ A., \qquad (11)$$

where R represents the total machine friction in pounds draw-bar pull, W_d represents the tons weight on the drivers, and A represents the number of driving axles.

Column No. 9 is the machine friction expressed in pounds of draw-bar pull, and is calculated by the formula used by the American Locomotive Company for the power consumed between the cylinders and the engine draw-bar. The formula is

$$R = 22.2\ W_d, \qquad (12)$$

where R represents the total machine friction in pounds draw-bar pull, and W_d represents the tons weight on the drivers.

TABLE X.

MACHINE FRICTION
OF
STEAM LOCOMOTIVES.

Item	Type	Wt. on drivers Tons.	No. of driving axles.	Tons Wt. per Axle
1	2	3	4	5
1	2-8-0	81.30	4	20.33
2	2-8-0	82.25	4	20.56
3	2-10-2	116.83	5	23.37
4	4-4-2	43.93	2	21.96
5	4-4-2	49.60	2	24.80
6	4-4-2	32.68	2	16.38
7	4-4-2	55.00	2	27.50
8	2-8-0	86.50	4	21.63
9	4-4-0	27.00	2	13.50
10	4-4-2	55.00	2	27.50
11	0-8-8-0	188.40	8	23.30
12	2-8-8-2	185.00	8	23.10
13	0-8-8-0	204.50	8	25.60
14	4-6-2	94.80	3	31.60
15	2-8-0	105.50	4	26.40
16	4-6-2	98.90	3	32.60
17	0-8-8-0	204.40	8	25.60

TABLE X. (continued)

MACHINE FRICTION
OF
STEAM LOCOMOTIVES.

Item	Minimum Friction Loss, %. Avg. Test.	Fric. Loss D.B.Pull Avg. Lbs. Test.	A.R.E.A. Frict.D.B.P.= $18.7W_d$ + 80 A. Lb.	A.L.Co. Frict.D.B.P.= W_d x 22.2 Lb.
1	6	7	8	9
1	11.3	1710	1840	1810
2	12.0	1822	1850	1830
3	14.0	3744	2582	2590
4	18.5	1035	983	977
5	19.0	1968	1087	1100
6	12.25	763	770	725
7	15.0	1496	1190	1220
8	21.2	3530	1940	1920
9	10.21	465	665	598
10	18.0	1654	1190	1220
11	16.1	7360	4163	4145
12	21.8	10360	4100	4110
13	11.5	7600	4464	4540
14	13.8	2110	2010	2105
15	13.2	3333	2295	2342
16	13.8	2610	2090	2190
17	—	5100	4470	4540

The following notes pertain to the tests of the locomotives which are tabulated in the table on pages 74 and 75.

ITEM No. 1.

Locomotive No. 734, L.S.& M.S. R.R. 2-8-0, Simple.

Test was made on the Pennsylvania testing plant at St. Louis, Mo. in 1904.

The machine efficiency of this locomotive was very high, being in some cases over 90%, which may be accounted for, in part, by the fact that it had been in service a long time and was consequently well worn. It was equipped with grease cups on the rods, and oil was used in the driving-box cellars.

ITEM No. 2.

Locomotive No. 585, M. C. R.R., 2-8-0, 2 cyl. X-Comp.

Test was made on the Pennsylvania testing plant at St. Louis, Mo. in 1904.

The machine efficiency was uniformly high and ranged from 78.98% to 94.16%. Oil lubrication.

ITEM No. 3.

Locomotive No. 929, A.T.& S.F. R.R. 2-10-2, 4 cyl. Tan.Comp.

Test was made on the Pennsylvania testing plant at St. Louis, Mo. in 1904.

The machine efficiency ranged from 80.33% to 90.48%.

While the speeds were low, these figures appear remarkably high for a locomotive having so many journals and moving parts. Oil lubrication was used, but due to the small range of loads and speeds covered in the test, its graphical representation has been omitted.

ITEM No. 4.

Locomotive No. 2512, P.R.R. 4-4-2 4 cyl. Bal.Comp.

Test was made on the Pennsylvania testing plant at St. Louis, Mo. in 1904.

The machine efficiency ranged from 74.74% to 89.45%. Oil lubrication was used.

ITEM No. 5.

Locomotive No. 535, A.T.& S.F. 4-4-2 4 cyl. Bal.Comp.

Test was made on the Pennsylvania testing plant at St. Louis, Mo. in 1904.

The machine efficiency ranged from 61.53% to 87.84%. Grease lubrication was used, therefore graphical representation of the frictional draw-bar pull has been omitted.

ITEM No. 6.

Locomotive No. 628, Hanover, 4-4-2, 4 cyl. Bal. Comp.

Test was made on the Pennsylvania testing plant at St. Louis, Mo. in 1904.

The machine efficiency ranged from 78.94% to 94.08%. Oil lubrication was used.

ITEM No. 7.

Locomotive No. 3000, N.Y.C.& H.R.RR. 4-4-2, 4 cyl.Bal.Comp.

Test was made on the Pennsylvania testing plant at St. Louis, Mo. in 1904.

The machine efficiency ranged from 68.47% to 93.95%. At a nominal speed of 80 R.P.M. and a nominal cut-off of 35%, the machine efficiency was 68.47%. At the same speed, but with a nominal C.O. of 45%, the machine efficiency was 84.89%.

ITEM No. 8.

Locomotive No. 1499, P.R.R. 2-8-0, Simple.

Test was made on the Pennsylvania testing plant at St. Louis, Mo. in 1904.

At a given speed, the general law governing the variation of the friction measuring factors was not apparent. In fact, the machine friction appeared to be constant for any given speed. The machine efficiency ranged from 72.89% to 84.82%, which may be accounted for by the newness of the locomotive and by the fact that it was lubricated throughout with grease. Due to the grease lubrication, its graphical representation has been omitted.

ITEM No. 9.

Locomotive No. 1, Purdue University, Schenectady No. 1, 4-4-0, Simple.

Tests were made at Lafayette, Indiana.

Tests were made with oil as a lubricant. The machine efficiency varied from 84.35% to 92.62%.

ITEM No. 10.

Locomotive No. 5266, P.R.R., 4-4-2, Simple, 2 cyl.

Test was made on the Pennsylvania testing plant at Altoona, Pa. in 1909.

Throughout this series of tests, the driving axle bearings were lubricated with oil. The main and side rods, except the front end of the main rods, were lubricated with hard grease. The cylinders were lubricated with oil by means of a sight-feed lubricator.

ITEM No. 11.

Locomotive No. 993, N.& W. R.R. 0-8-8-0, Mallet Comp.

Test was made on Road- See Railway Age Gazette May 19, 1911.

The data for this locomotive as presented in the above table, is the average only. The mechanical efficiency was quite uniform, varying from 81.4% minimum to 88.6% maximum; and the average of 83.9% is unusually high for a Mallet type locomotive. No correction was made for grade and tender resistance.

ITEM No. 12.

Locomotive No. 998, N. & W. R.R. 2-8-8-2, Mallet Comp.

Test was made on Road- See Railway Age Gazette, May 19, 1911.

The data presented in the above table is the average, based on six trips. No correction was made in report for grade and tender resistance. Oil lubrication was used.

ITEM No. 13.

Locomotive No. 2600, Erie R.R., 0-8-8-0, Mallet Comp.

Test was made on Road- See A.E.& R.J. June '08, p.213.

No corrections were made for grade and tender resistance. Oil lubrication was used.

The results shown are the average for three runs.

ITEM No. 14.

Locomotive No. 7166, P. R.R. 4-6-2, 2 cyl. Simple.

Test was made on Pennsylvania testing plant at Altoona, Pa. in 1910.

Oil lubrication was used. The results shown are the average for fourteen tests.

ITEM No. 15.

Locomotive No. 1134, P.R.R., 2-8-0, 2 cyl. Simple.

Test was made on Pennsylvania testing plant at Altoona, Pa. in 1911.

Oil lubrication was used. The results shown are the average for five tests.

ITEM No. 16.

Locomotive No. 3395, P.R.R. 4-6-2, 2 cyl. Simple.

Test was made on Pennsylvania testing plant at Altoona, Pa. in 1911.

Oil lubrication was used. The results shown are the average for thirty-nine tests.

ITEM No. 17.

Locomotive No. 3397, P.R.R. 0-8-8-0, 4 cyl. Mallet Comp.

Test was made on Road, 1911.

Grade has been eliminated by making tests in both directions, all of which are averaged and shown here.

From the tabulated figures given above in connection with the tables under test of each locomotive, an idea can be obtained of the probable loss in engine friction under average conditions. These figures seem to confirm the fact that the machine friction remains constant as the speed increases, which is consistent with the general laws of rubbing friction for speeds greater than 25 feet per minute.

The plotted points in Fig. 18 represent graphically the average frictional resistance in pounds pull of the several locomotives which are tabulated in Table X. All the plotted points are numbered to correspond with the items tabulated in that table, and are representative of those locomotives which were equipped with oil cellars and hard grease cups on the rods.

The line "AB" which is shown in this figure, is the graphical representation of $R = 22.2\ W_d$, where R is the resistance in pounds of draw-bar pull, and W_d is the tons weight on the drivers of any locomotive. With the exception of point No. 15, which corresponds to the data furnished for Item No. 15 in Table X, we can say that the curve "AB" is a fair representation of how machine friction varies with the weight on drivers.

The curves in Fig. 19 represent graphically how the results of tests for machine friction in pounds per ton weight on drivers vary with speed. The curve "CD" in this figure

represents graphically the formula $R = 22.2\ W_d$, which, as previously stated, depicts the relation between R and W_d, independent of speed. These curves are designated to correspond with the items given in Table X. In these, oil as a lubricant was used in the cellars and hard grease was used on the rods.

The superheater locomotive has often been accused of having a greater frictional resistance in its mechanism than a duplicate non-superheating locomotive under like conditions, due to the difficulty of keeping the rubbing surfaces of the valve and valve-seat, and cylinder wall and piston, in the same lubricated condition as in a locomotive using saturated steam. But due to a lack of sufficient data, no attempt has been made to separate the frictional characteristics of superheater from non-superheater locomotives, as it is assumed that in either case, with perfect lubrication, the results should be comparable.

It would seem from this exhibition of curves, that the line "CD" is probably as good an average as could be expected, for with the data at hand no definite laws regarding machine friction can be formulated for locomotives in general. Nor can a law be derived by assuming them to be divided into classes, as 4-coupled, 6-coupled, and 8-coupled locomotives, and applying an acceptable law to each class.

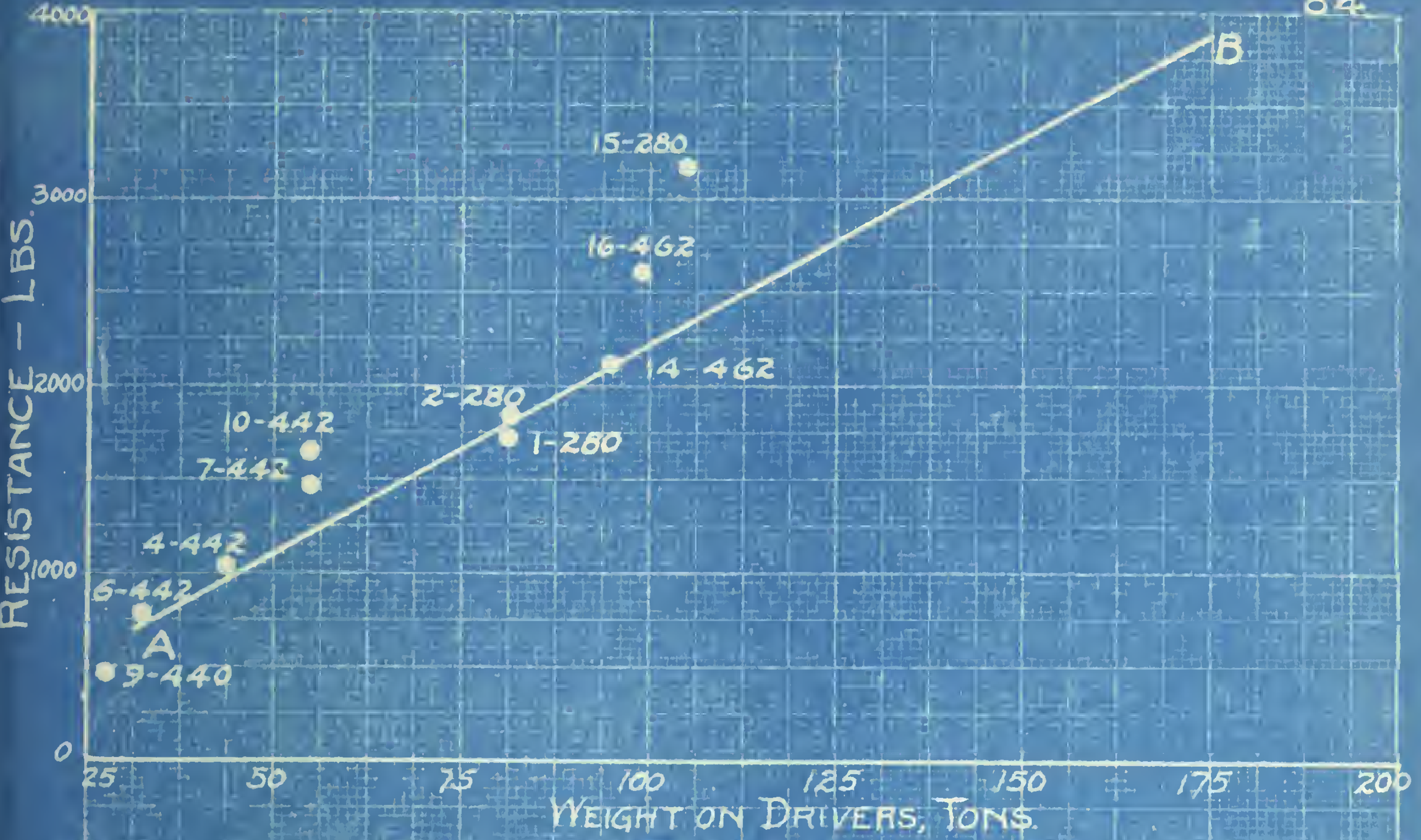
RESISTANCE - LBS.
4000
3000
2000
1000
0
B
15-280
16-462
14-462
2-280
1-280
10-442
7-442
4-442
6-442
A
9-440
25
50
75
100
125
150
175
200
WEIGHT ON DRIVERS, TONS.

FIG. 18.

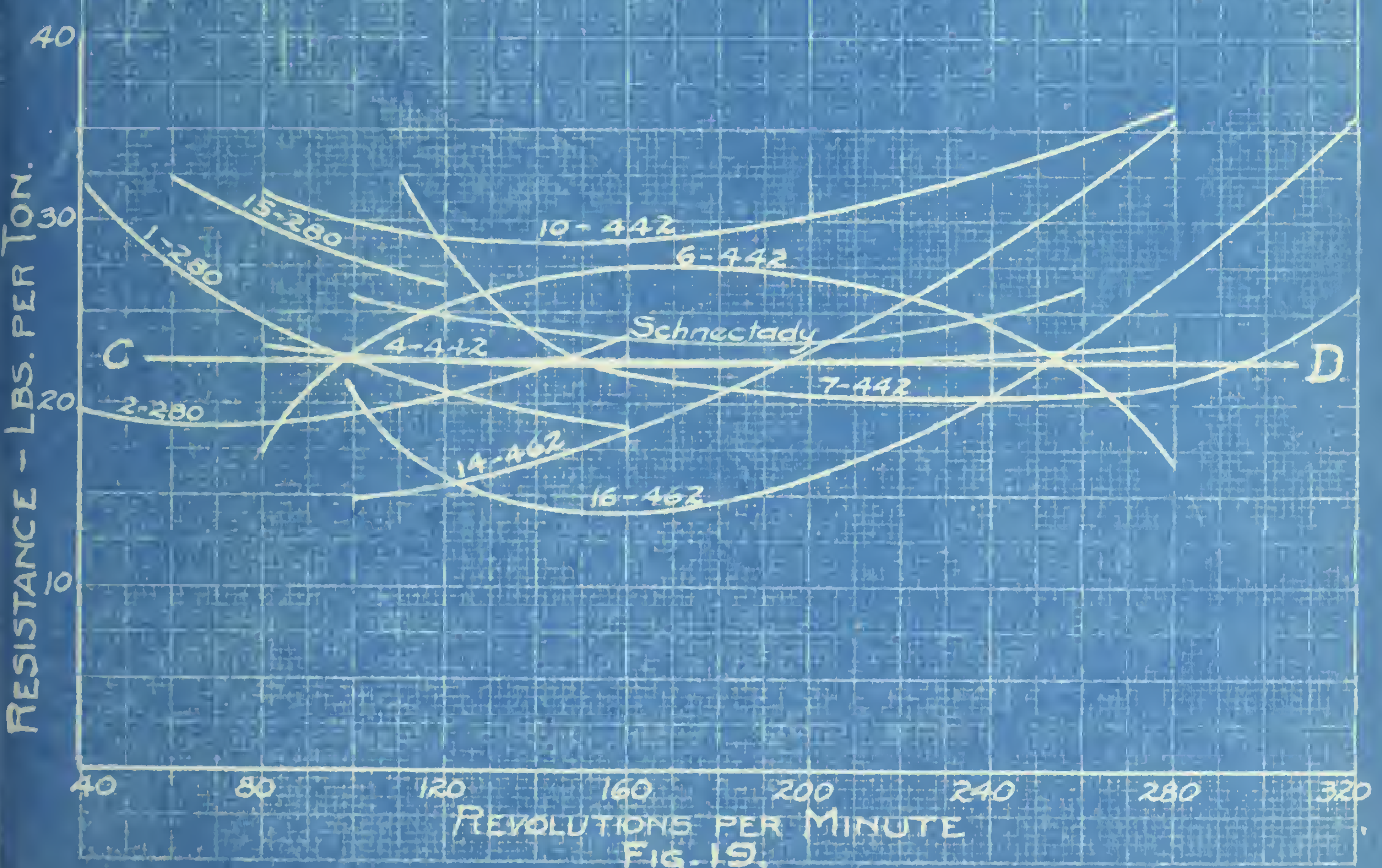
RESISTANCE - LBS. PER TON.
40
30
20
10
15-280
1-280
10-442
6-442
Schnectady
C
D
4-442
7-442
2-280
14-462
16-462
40
80
120
160
200
240
280
320
REVOLUTIONS PER MINUTE

FIG. 19.

Of the two formulae, $R = 22.2\ W_d$ and $R = 18.7\ W_d + 80\ A$, the former is much the simpler for determining machine friction in pounds of draw-bar pull, and it gives results which are more consistent with those obtained under actual test conditions. In this formula it is assumed that the number of axles is a function of the weight of the locomotive and that the weight per axle is a constant quantity.

The formula $R = 22.0\ W_d$ instead of $R = 22.2\ W_d$, has been used throughout this treatise for determining the value of machine friction in pounds of draw-bar pull for steam locomotives.

APPENDIX III

STEAM TRAIN RESISTANCE.

STEAM TRAIN RESISTANCE.

In modern railroad service it is frequently necessary to predetermine the force a steam locomotive must exert to draw a given number of cars with a given load, at a given speed.

A great many experiments have been made to determine values of train resistance, but the results obtained have generally been conflicting, possibly due to rather crude apparatus or a lack of care in performing tests with first-class apparatus, or through some neglect to observe all conditions and properly analyze the existing data.

Train resistance is generally defined as the resistance encountered in the movement of trains at uniform speed on straight level track in still air. It will be well to divide this resistance into locomotive and tender resistance, and car resistance.

The locomotive and tender resistance may be subdivided as follows:

A. MACHINE FRICTION OF THE MOVING PARTS OF THE LOCOMOTIVE, INCLUDING ROLLING FRICTION OF THE DRIVERS.

This resistance is equal to 22.0 pounds per ton on drivers. A detailed discussion of this is given in the appendix on Steam Locomotive Friction.

B. RESISTANCE OF LOCOMOTIVE TRUCKS.

The resistance of the leading and trailing trucks of a locomotive is assumed to be the same as for the car axles in

the train which have an equivalent axle load. This is expressed by the formula

$$R = \frac{V + 41}{0.684\frac{W}{A} + 3.8} \qquad (13)$$

where

R represents the resistance in pounds per ton,

V represents the speed in miles per hour,

W represents the load in tons, and

A represents the number of axles carrying the load W.

This proposed equation is taken from the University of Illinois train resistance data, and may be accepted as general in its application.

C. ATMOSPHERIC RESISTANCE.

In this discussion of atmospheric resistance, or that resistance offered by still air to the forward movement of locomotive and tender, it is desirable to state the equivalent effect of the air in pounds pull at the tender draw-bar.

The experiments*, which have been performed to determine the law governing the variation of air resistance with speed, have been limited not only in number, but the conclusions have been unsatisfactory and uncorroborative, especially for steam railroad practice.

Atmospheric resistance is but a small part of the total resistance when low speeds and heavy trains are considered. But at high speeds this resistance is predominant for light or for single car trains.

The results of the experiments conducted at Purdue University by Dr. W. F. M. Goss and published in his book "Locomotive Performance" are the results of tests performed

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*Some of these are:

1. The Purdue University Tests, made in 1897.
2. The tests made by Prof. F. E. Nipher in 1898, and published in Vol. 8 of the St. Louis Academy of Science.
3. The Berlin-Zossen Tests, made in 1903.
4. The Electric Railway Commission Tests, made in 1904.
5. Tests made by J. A. F. Aspinall in 1902, Transactions I. C. E.

on small model cars, similar to freight cars in outline and proportion, but about 1/1024 of the cross-sectional area. Had the dimensions of the model car been equal to those of a full-sized car, the results would have been accepted unquestioned. But since the results actually observed from the small models are assumed to be proportional to those expected from actual cars in service, the question arises as to whether the effect of the air upon solids varies directly with the area of the exposed flat surface, or with the perimeter of the same surface, or with the product of the two.

The results of these tests at Purdue University justified the use of the following equation as representing the variation of atmospheric resistance with velocity:

$$R = P\ A\ V^2 \qquad (14)$$

where

R = total equivalent head-end resistance at tender draw-bar, pounds.

P = pressure per square foot on a flat surface, pounds.

A = cross-sectional area of locomotive, square feet.

V = velocity of train in miles per hour.

If we substitute in equation 14 the values which were justified by the results obtained from the Purdue experiments, we have

$$\begin{aligned} R &= 0.00108 \times 103.5 \times V^2 \\ &= 0.11\ V^2 \qquad (15) \end{aligned}$$

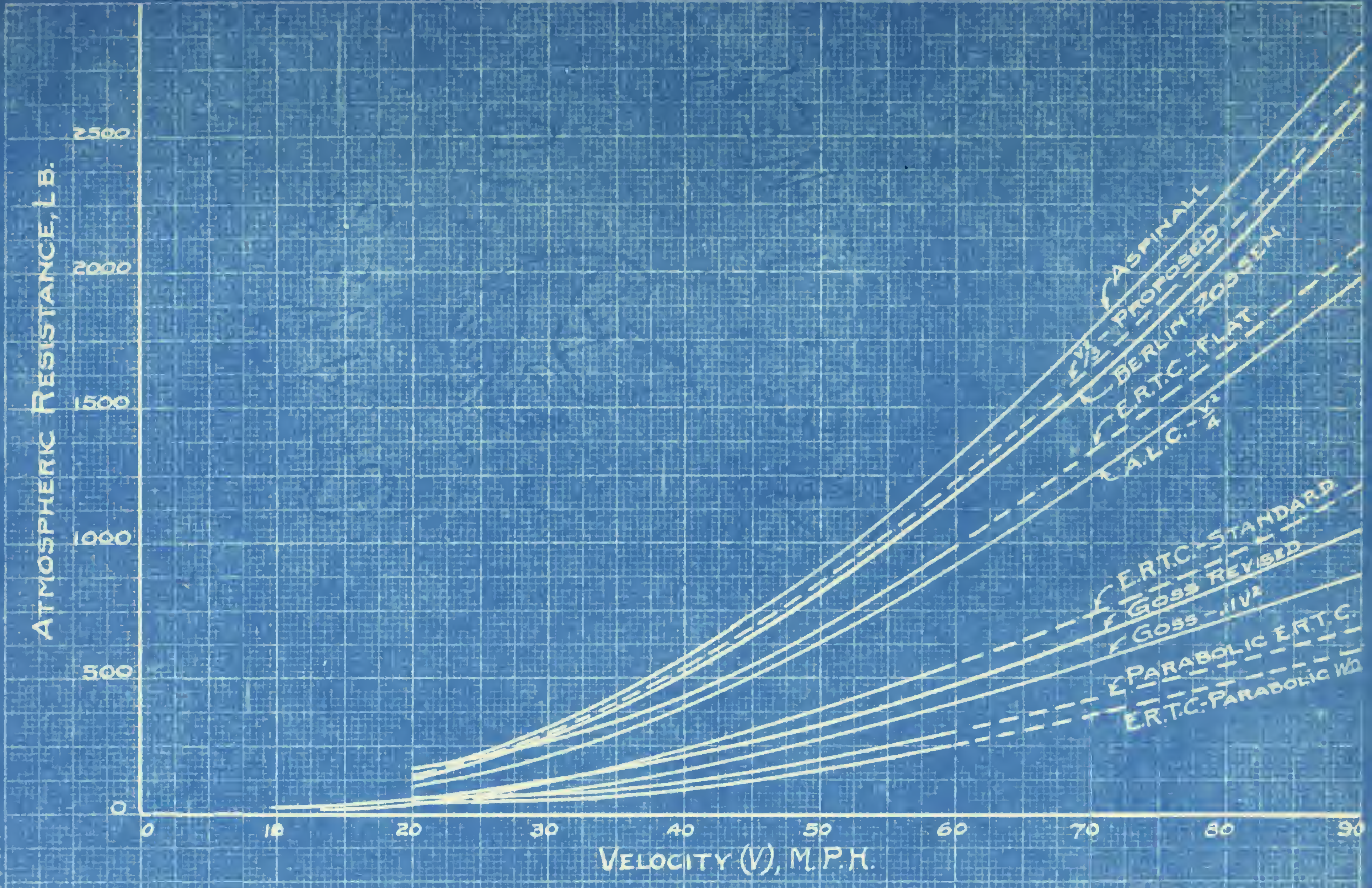

Fig. 20. Variation of Atmospheric Resistance with Speed.

Equation 15 is used by Dr. Goss as expressing the relation existing between atmospheric resistance and velocity for a locomotive and tender running at the head of a train. But today, modern equipment changes the value of A from 103.5 as in equation 15, to 120, which makes it necessary to revise that equation to

$$R = 0.13\ V^2 \tag{16}$$

in which R and V represent the same variables as before. Graphs of equations 15 and 16 are shown in Fig. 20, marked "Goss" and "Goss Revised", respectively.

The tests performed in 1904 by the Electric Railway Test Commission and published by them in 1905, gives the results of atmospheric resistance tests which are shown by four curves in Fig. 20 and marked "E.R.T.C." These curves are plotted on a basis of 120 square feet projected area of front end, and are the results of using four different shaped vestibules; the parabolic-wedge, the parabolic, the standard, and the flat, each operating through a system of levers to a dynamometer where the direct atmospheric pressures were measured.

The data from which these latter curves are derived are not representative of an exact empirical law of variation between atmospheric resistance and velocity, but only of the general tendency of such a law, due to the scattered and irregular position of the plotted points. The curves, drawn

through these points by the method of least squares, show that the flat surface form of vestibule gives the greatest resistance, the standard form is next in order, and then the parabolic and the parabolic-wedge in order, respectively.
In the tests of the flat vestibule a maximum speed of only 50 miles per hour was reached, as it was impossible with the power at hand to force the car with such a vestibule above this speed.

These experiments could hardly be accepted as conclusive, but they do show that atmospheric resistance, for speeds up to 60 miles per hour, varies as the square of the velocity.

The results of one of the most complete experiments on atmospheric resistance, are found in the report* of tests conducted on the German military railroad during the months of September, October, and November, 1903, and which are commonly known as the Berlin-Zossen tests.

In these tests the assumption was made that train resistance other than air might be put into the form

$$A + BV \qquad (17)$$

A and B being constants.
When air resistance was included, the expression then took the form

$$A + BV + CV^2 \qquad (18)$$

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* Published by the "Studien-Gesellschaft für Elektrische Schnellbahnen", Berlin.

and the vital point to be determined was the coefficient C for a normal plane surface. These tests were especially planned with respect to the determination of this quantity, and the results thus obtained are probably by far the most trustworthy yet reached.

A most essential feature in the consideration of atmospheric resistance is the effect on the coefficient of V^2 produced by changes in shape of the head-end. Anticipating the fact that a wedge shaped or parabolic shaped head-end would very materially reduce the atmospheric resistance, attention was given to it by using detachable vestibules, only to a less extent than in the tests performed by the Electric Railway Test Commission.

The net result of the Berlin-Zossen tests was to give

$$R' = 0.0052\ V^2 \qquad (19)$$

for a flat surface when the pressure is taken in kilograms per square meter, and the speed in kilometers per hour. The value of a similar coefficient as proposed by Newton* and used by artillerists for projectiles is,

$$R' = \frac{D}{2g} V^2$$

---

* Fur further analysis see "A Method of Measuring the Pressure at any Point on a Structure, due to Wind Blowing against that Structure", by Prof. F. E. Nipher in the Transactions of the St. Louis Academy of Science, Vol. 8.

where R' is the pressure in kilograms per square meter, D is the weight of one cubic meter of air, and V the speed in kilometers per hour. If we assume an average value of 1.293 for D, we have

$$R' = 0.0051\ V^2$$

The facts thus derived from two entirely different lines of experiment are in substantial concurrence.

Equation 19 when reduced to the English system of units, gives

$$R'' = 0.0027\ V^2 \qquad (20)$$

where

R'' = resistance in pounds per square foot
and V = velocity in miles per hour.

If we assume a head-end area of 120 square feet, then equation 20 may be written

$$R = 0.324\ V^2 \qquad (21)$$

where

R = total head-end resistance in pounds draw-bar pull for the flat surface,
V = velocity in miles per hour.

Equation 21 is plotted and shown in Fig. 20 where it is marked "Berlin-Zossen" and is representative of the variation of atmospheric resistance with speed for a flat surface.

The American Locomotive Company use equation 14 for determining atmospheric resistance by substituting in it the

following values:

$$P = 0.002$$

and $$A = 120.0$$

which reduces it to

$R = 0.24\ V^2$ for an area of 120 square feet,

or approximately,

$$R = \frac{V^2}{4} \qquad (22)$$

in which

R = atmospheric resistance in pounds pull at tender draw-bar,

V = velocity in miles per hour.

Equation 22 is shown as a curve in Fig. 20 and is marked as "A.L.C.- $\frac{V^2}{4}$".

Mr. J. A. F. Aspinall, in the results* of his tests made on the London and North-Western Railway in England, gives the variation of atmospheric resistance with speed in the form shown by equation 14.

He experimentally ascertained the relation between velocity and atmospheric resistance by means of collectors and anemometers. If in equation 14 we substitute his result wherein

$$P = 0.003,$$

and if

$$A = 120.0$$

---

* Published in the Transactions of I.C.E. in 1902.

we have

$$R = 0.36\ V^2 \tag{23}$$

in which

R = atmospheric resistance in pounds pull at tender draw-bar,

V = velocity in miles per hour.

Equation 23 is shown as a curve in Fig. 20 and is marked as "Aspinall".

The atmospheric resistance offered by the sides of a train is thought to be comparatively small, although there is a lack of data to substantiate this idea. It seems to be the opinion of experimenters that if there is an appreciable side resistance, it is not dependent so much upon the action of still air as upon the direction and strength of prevailing winds. Especially is this so with the modern type of passenger equipment where the train is vestibuled and the windows are flush with the sides of the car.

It should be noted that in no other experiments with actual cars have the high velocities recorded in the Berlin-Zossen tests been reached, so that these results are the only ones not subject to the errors of extrapolation. The results are not only applicable in connection with electric cars, but they are also applicable to steam locomotives and trains.

There is no doubt but that the atmospheric resistance offered to all high speed trains would be reduced materially

if the locomotive were enclosed in a housing, and if care were taken, as in foreign countries, to remove all unnecessary irregularities. From the standpoint of atmospheric resistance nothing worse can be imagined than the American locomotive with its numerous projections.

After careful study of the experiments above cited, the curve marked "Proposed" in Fig. 20, whose equation is

$$R = \frac{V^2}{3} \tag{24}$$

where

R = atmospheric resistance in pounds of draw-bar pull, for an area of 120 square feet,

and V = velocity of train in miles per hour,

is suggested by the writer as representing the variation in atmospheric resistance with speed, and has been used throughout this article wherever atmospheric resistance has been taken into consideration.

To the writer it seems that a very successful method of determining head-end atmospheric resistance of steam trains would be; to either put a locomotive shape, which would operate through a system of levers connected to a dynamometer, on an electric car, or, to first test a locomotive in a locomotive testing plant, then test it out on the road, being careful to select a calm day for the road test, or to average the results from opposing runs with moderate wind.

D. TENDER RESISTANCE.

The resistance which the tender offers to the movement of a train is measured in pounds of draw-bar pull and is calculated the same as for the cars in the train, with the exception that the weight of the tender is always taken at 70 per cent of its maximum loaded weight in order to correct for the continuous fluctuations in the weights of coal and water. This is expressed by the equation

$$R = \frac{V + 41}{.12W_m + 3.8} \qquad (25)$$

where

R = resistance in pounds per ton

V = velocity of train in miles per hour

W_m = maximum loaded weight (light weight plus capacity) of tender in tons.

E. CAR RESISTANCE.

1. Freight Car Resistance.

Experiments in train resistance have disclosed the fact that the resistance is not only a function of speed, but also a function of the car weight or axle load. However, since practically all American freight cars are of four axles, either form of expression is acceptable.

Ordinarily, train resistance is expressed as a curve or an equation which defines the relation existing between the resistance and the speed. Such a relation is satisfactory,

provided the car weights or axle loads are the same, but if they fluctuate, then a separate expression for each loading is required. Since we know that car weights and capacities are decidedly irregular, it becomes necessary to express the variation of train resistance with speed and with the average gross car weights. Professor E. C. Schmidt has done this for trains running at uniform speed on tangent level track when the air temperature is above 30°F., by expressing the relation existing between train resistance in pounds per ton and the average gross weight per car in tons for different speeds in miles per hour. In this connection, there is no better presentation of facts than those which he sets forth in bulletin 43 published by the Engineering Experiment Station of the University of Illinois, wherein is exhibited the table shown on page 101.

The results of the tests may also be approximately expressed by the following single empirical equation in which the resistance is stated in terms of both velocity and car weight, as

$$R = \frac{V + 30.6 - .031\ W}{4.08 + 0.152\ W} \tag{26}$$

where

R = freight car resistance, pounds per ton.

V = velocity in miles per hour,

W = average weight of car, tons.

The resistance values listed in the table on page 101 as well as all others which are and will be given, refer to uniform velocity on a level tangent track. It is an easy matter, as is shown elsewhere, to determine by calculation the correction to be added or subtracted for an up or down grade.

Since train resistance is a function of speed, and also a function of the car weights, we assume that the composition of the 2000 ton and the 4000 ton freight trains, which are described elsewhere, are uniform; that is, for the freight train the assumption is that the average gross weight per car for either train is 44.5 tons, thereby requiring the first train to consist of 45 cars, and the second train to consist of 90 cars. Then from Professor Schmidt's experiments, the relation between resistance and speed for a car weight of 44.5 tons may be shown by an equation in which

$$R = 3.82 + 0.031\ V + 0.0014\ V^2 \qquad (27)$$

where

R = resistance in pounds per ton

V = velocity in miles per hour.

The results derived from this equation form a basis on which draw-bar pull may be calculated for trains running at uniform velocity.

TABLE XI.

Values of resistance at various speeds and for trains of different average weights per car.

SPEED MILES PER HOUR	TRAIN RESISTANCE — POUNDS PER TON													SPEED MILES PER HOUR
	COLUMN HEADINGS INDICATE THE AVERAGE WEIGHTS PER CAR													
	15 TONS	20 TONS	25 TONS	30 TONS	35 TONS	40 TONS	45 TONS	50 TONS	55 TONS	60 TONS	65 TONS	70 TONS	75 TONS	
[illegible]	7.6	6.8	6.0	5.4	4.8	4 4	4.0	5.1	3.5	3.3	3.2	3.1	3.0	[illegible]
6	7.7	6.9	6.1	5.5	4 9	4 4	4.1	3.8	3.5	3 3	3.2	3.1	3.0	6
7	7.8	7.0	6.2	5.5	5.0	4.5	4.1	3.8	3.6	3.4	3.2	3.1	3.1	7
8	8.0	7.1	6.3	5.6	5.0	4.6	4.2	3.9	3.6	3.4	3 3	3.2	3.1	8
9	8.1	7.1	6 4	5.7	5.1	4.6	4.2	3.9	3.6	3.4	3.3	3.2	3.1	[illegible]
10	8.2	7.3	6.5	5.8	5.2	4.7	4.3	4.0	3.7	3.5	3.3	3.2	3.2	10
11	8.3	7.4	6.6	5.9	5.3	4.8.	4.3	4.0	3.7	3.5	3.4	3.3	3.2	11
12	8.4	7.5	6.7	6.0	5.4	4.8	4.4	4.0	3.8	3.6	3.4	3.3	3.3	12
13	8.6	7.6	6.8	6.1	5.5	4.9	4.5	4.1	3.8	3.6	3.5	3.4	3.3	13
14	8.7	7 8	6.9	6.2	5.5	5.0	4.5	4.2	3.9	3.7	3.5	3.4	3.4	14
15	8.8	7.9	7.0	6.3	3.6	5.1	4.6	4.2	3.9	3.7	3.6	3.5	3.4	15
[illegible]	9.0	8.0	7.1	6 4	5.7	5.1	4.7	4.3	4.0	3.8	3.6	3.5	3.5	16
11	9 1	8.1	7.2	6.5	5.8	5.2	4.8	4 4	4.1	3.9	3.7	3.6	3.5	17
18	9.3	8.3	7.4	6 6	5.9	5.3	4.8	4.5	4.1	3.9	3 7	3.7	3.6	18
19	9.4	8.4	7.5	6.7	6.0	5.4	4.9	4.5	4.2	4.0	3.8	3.7	3 6	19
20	9.6	8 5	7.6	6.8	6 1	5.5	5.0	4.6	4.3	4.0	3.9	3 8	3 7	20
21	9.7	8.7	7.7	6.9	6.2	5.6	5.1	4.7	4.3	4.1	3.9	3.9	3.8	21
22	9.9	8.8	7.9	7.0	6.3	5.7	5.2	4.8	4.4	4.2	4.0	3 9	3.8	22
23	10.0	9.0	8.0	7.1	6 4	5.8	5.3	4.9	4.5	4.3	4.1	4.0	3.9	23
24	10.2	9.1	8 1	7 3	6 6	5.9	5.4	4.9	4.6	4.3	4.2	4.1	4.0	24
25	10.4	9 3	8.3	7 4	6 7	6.0	5.5	5.0	4 7	4.4	4 2	4.1	4.0	25
26	10.5	9.4	8.4	7.5	6.8	6.1	5.6	5.1	4 8	4.5	4.3	4.2	4.1	26
27	10.7	9.6	8.5	7 7	6.9	6.2	5.7	5.2	4 8	4.6	4.4	4.3	4.2	27
28	10.9	9 7	8.7	7 8	7.0	6.3	5.8	5.3	4.9	4.7	4.5	4 4	4 3	28
29	11.1	9.9	8.8	7.9	7.1	6.5	5 9	5.4	5.0	4.8	4 6	4.5	4 4	29
30	11 3	10.0	9.0	8.0	7.3	6.6	6.0	5.5	5.1	4.9	4.7	4.5	4 5	30
31	11 4	10.2	9.1	8.2	7 4	6.7	6.1	5.6	5.2	5.0	4.8	4.6	4 5	31
32	11.6	10.4	9.3	8.3	7 5	6.8	6.2	5.8	5.3	5.0	4.9	4.7	4.6	32
33	11.8	10 8	9 4	8.5	7.6	7.0	6.3	5 9	5.4	5.2	5.0	4.8	4 7	33
34	12.0	10.7	9.6	8.6	7.8	7.1	6 5	6.0	5.5	5.3	5.1	4.9	4.8	34
35	12.3	10.9	9.7	8.8	7.9	7.2	6.6	6.1	5.7	5.4	5.2	5.0	4.9	35
36	12.5	11.1	9.9	8.9	8.0	7.4	6.7	6.2	5.8	5.5	5.3	5.1	5.0	36
37	12.7	11 2	10.0	9.0	8.2	7.5	6.9	6.4	5.9	5.6	5.4	5.2	5.1	37
38	12.9	11.4	10.2	9 2	8.3	7.6	7.0	6.5	6.0	5.7	5.5	5.3	5.2	38
39	13.1	11.6	10.4	9.4	8.5	7.8	7.1	6.6	6.2	5.8	5.6	5.4	5.3	39
40	13.4	11.8	10.6	9.5	8.6	7.9	7.3	6.8	6.3	6.0	5.7	5.6	5.5	40

2. Passenger Car Resistance.

At present the predetermination of passenger car resistance which would be applicable to the American equipment of the present day, is decidedly questionable if fairly accurate results are concerned.

One of the most thorough investigators of this subject is Mr. J. A. F. Aspinall, who in 1892 conducted some very extensive tests on the L. and N. W. R.R. in England to determine the resistance in pounds per ton of bogie coaches. Although these tests had to do with passenger equipment, their value from an American standpoint is questionable. For instance, Mr. Aspinall's curve of passenger car resistance when plotted against speed, as shown by curve No. 1 on page 103, is a fair average of the family of curves when considered in the velocity range of 10 to 30 miles per hour, but at higher speeds its course tends upwards, thereby diverging from the average course followed by the other curves. This rapid increase in the resistance at speeds above 30 miles per hour, and its separation from all the other curves shown, may be ascribed to the difference in the method of making the tests, wherein the resistances of the atmosphere and wind were not properly corrected for. Therefore, it is a question as to whether this curve should be given consideration above the speed of 35 miles per hour.

By an analytic study of the tests conducted by Mr. Aspinall and others, Mr. Carus-Wilson has presented some very

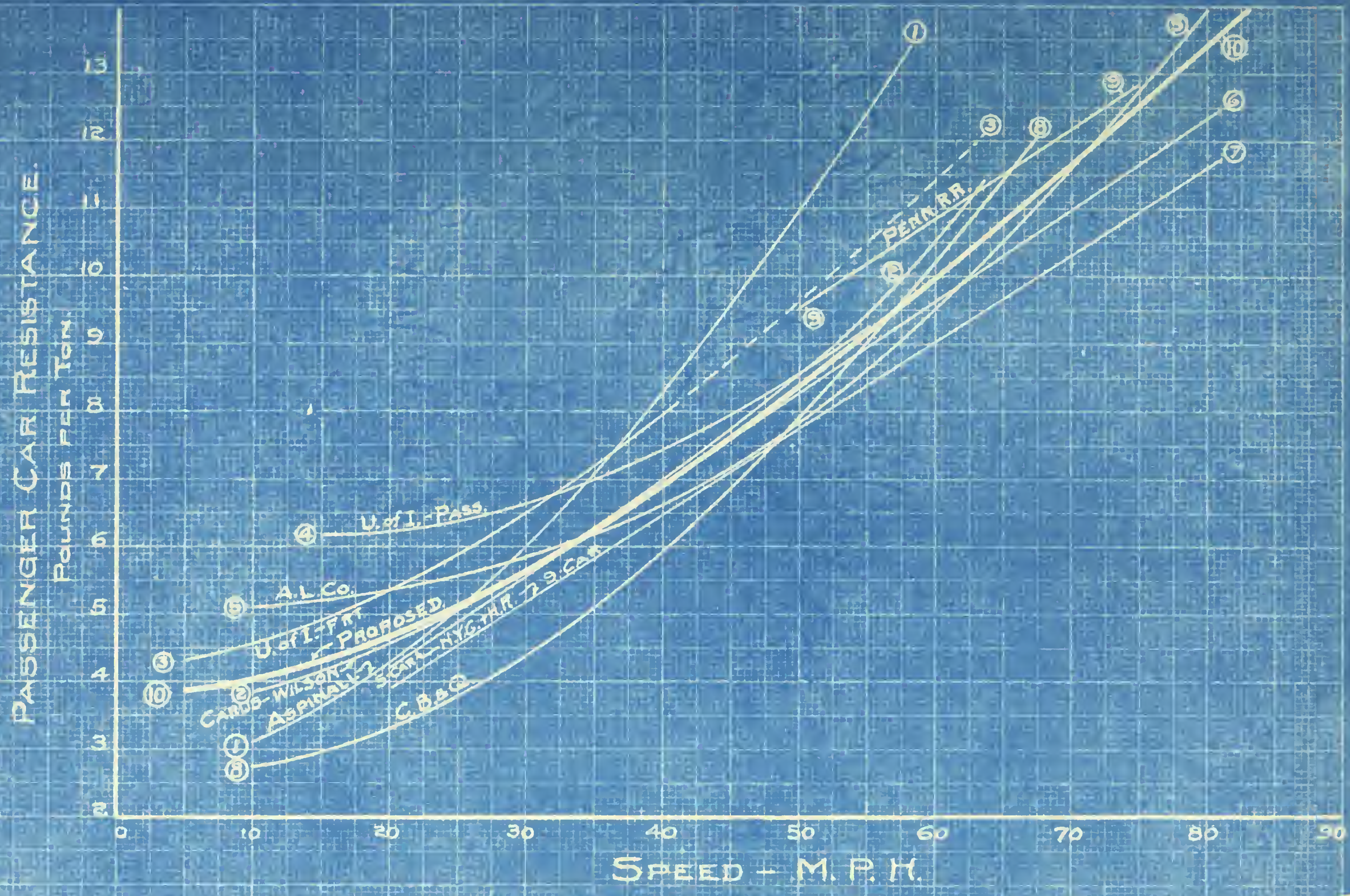

FIG. 21. VARIATION OF PASSENGER CAR RESISTANCE WITH SPEED.

good ideas regarding train resistance, although his lines of attack seem to be rather questionable in several instances, which might be due to the lack of proper data to check his theoretical calculations. It is to be noted that his results when plotted in the form of a curve, shown as curve No. 2, page 103, give a good average curve. Its equation is

$$R = \frac{50}{\sqrt{T}} + .03\ V + \frac{.002\ V^2}{T} A\left(1 + \frac{N - 1}{10}\right)$$

in which

R represents the resistance in pounds per ton

V represents the speed in miles per hour

T represents the weight of car in tons

N represents the number of cars in the train

A represents end cross-section in square feet

Curve No. 3, as shown in Fig. 21, is the average result of a number of tests performed by the University of Illinois, described in their Bulletin No. 43, referred to above. It represents the resistance of a 40 ton freight car, or the resistance of a car which has a 10 ton axle load.

For passenger work this might be considered as the resistance curve for a 12 wheel car, thus requiring it to have a total weight of 60 tons, which is representative of modern through passenger car equipment.

Curve No. 4, as shown in Fig. 21, is the result of one test performed by the University of Illinois on a 345 ton passenger train, which averaged 8.39 tons weight per axle.

The train was a mixed train of eight and twelve wheel cars.

No reliance can be put on the results of this test, due to the absence of a check on the results and to the impossibility of an analytic study of the controlling factors in passenger car resistance. It is to be noted that this curve has the highest values in resistance up to 30 m.p.h. of any of the curves presented in Fig. 21. At speeds above 30 m.p.h., the curve represents an average value for the whole group of curves.

Curve No. 5, as shown in Fig. 21, is the one used by the American Locomotive Company. This curve has higher than average resistance values for speeds below 30 m.p.h., and average values of resistance for speeds above 30 m.p.h.

Curves No. 6 and No. 7, as shown in Fig. 21, are the results of tests made in 1902 by the N.Y.C. & H.R. R.R. with 5 and 9 car passenger trains.

Curve No. 8, as shown in Fig. 21, represents the results of tests on the C. B. & Q. R.R.

Curve No. 9, as shown in Fig. 21, represents the results of tests on the P. R.R.

Curve No. 10, proposed by the writer, which is shown shown in Fig. 21, is probably as good a curve as can be had to represent the resistance of passenger cars irrespective of the weight per axle and the kind of trucks, that is, whether 4 wheel or 6 wheel trucks.

Neglecting the Aspinall curve above 35 m.p.h. due to its deviation from the general law followed by all the other curves, there is a zone ranging from 3 1/2 pounds per ton resistance at 10 m.p.h. to about two pounds per ton resistance at 70 m.p.h., in which Curve No. 10 has been drawn to represent average conditions. Although there is considerable variation among the curves in Fig. 21, they indicate a steady increase in the resistance as the speed increases.

Curve No. 10 may be represented by an equation, as

$$R = 3.5 + 0.038V + 0.0012 V^2$$

where R represents the resistance in pounds per ton, and S the speed in miles per hour.

To the writer, this curve seems to approximate average conditions, as undoubtedly the group of curves shown in Fig. 21 could hardly be comparable, as train resistance has too many varying and inseparable factors, viz: journal temperature, journal size and journal lubrication, wind direction and velocity, flange friction, etc., which are uncontrollable in ordinary train operation. The combination of several of these factors might easily increase or decrease the resistance as much as one pound per ton. Therefore, the conclusion reached is that curve No. 10, on page 103, is a fair average curve for representing passenger car resistance when the weight per car and kind of trucks are neglected. Hence, curve No. 10 on page 103, which has the following equation

$$R = 3.5 + 0.038 V + 0.0012 V^2 \qquad (28)$$

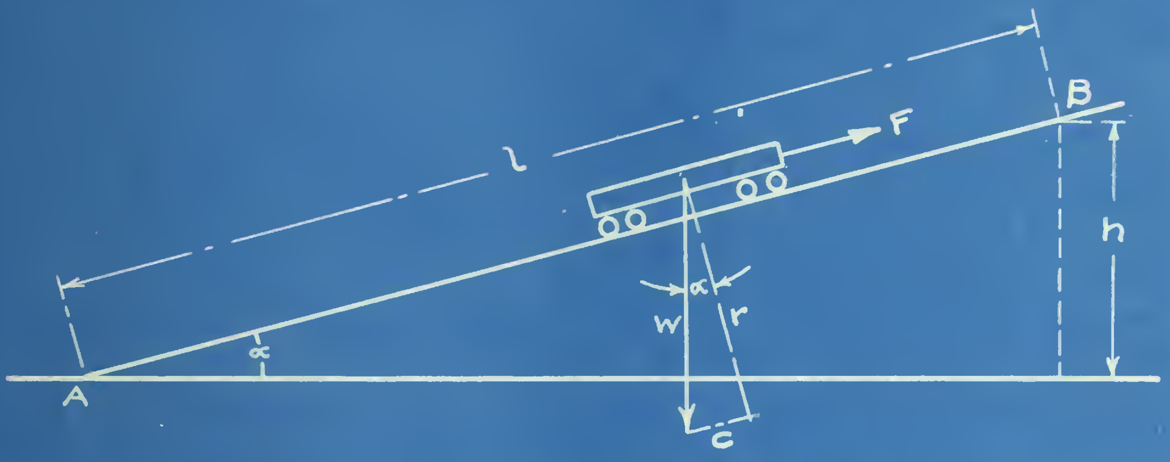

FIG. 22.

where R = resistance in pounds per ton

and V = velocity in miles per hour,

has been used by the writer in making all calculations pertaining to passenger car resistance.

F. ACCIDENTAL RESISTANCES.

1. Grade Resistance.

Grade resistance may be defined as the force opposing the elevation of a train due to a grade. A grade may be expressed either in percent or in feet rise per mile of track, if an approximation is permitted wherein the horizontal distance is assumed equal to the distance along the rail.

If the grade is expressed in per cent, then it is the ratio of distance the train is raised to the distance traveled. If the grade is 1 per cent and the distance traveled is one mile (5280 feet), then a 1 per cent grade is equivalent to 52.8 feet change in elevation.

For a train of 1 ton moving on a 1 per cent grade, we have

$$g = 2000 \times 0.01 = 20 \text{ pounds} \qquad (29)$$

where

g = grade resistance in pounds per ton of train for each 1 per cent grade.

In Fig. 22 a train is shown in equilibrium under the action of three forces due to

W = weight of train

r = normal reaction between wheel and rail

and F = draw-bar pull.

Accordingly,

$$F = c = W \sin\alpha = W\frac{h}{l}$$

Now for a train of one ton on a grade of one foot per mile, we have

$$F = 2000 \times \frac{1}{5280} \text{ lb.}$$
$$= 0.379 \text{ lb.} \qquad (30)$$

where

$F = g$ = grade resistance in pounds per ton of train for each foot rise per mile of track.

For a down grade, the resistance will be the same numerically, but will be negative.

2. Curve Resistance.

Curve resistance may be defined as the resistance caused by the friction due to the center plates, side bearings, grinding of the flanges against the rails, slipping of the wheels, etc. Evidently curve resistance varies with the degree of curve, the speed, and the superelevation of the outer rail.

In this article, curve resistance will be assumed equivalent to a retarding force of 0.5 pounds per ton for each degree of curve.

APPENDIX IV

PART I

SPEED-TIME CURVES
FOR
STEAM TRAIN SERVICE

SPEED-TIME CURVES
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STEAM TRAIN SERVICE.

A speed-time curve may be defined as a curve depicting the velocity of a moving body at successive intervals of time. In such a curve, the abscissae usually represent values of time in seconds, and the ordinates represent values of speed in miles per hour. For steam train service, it seems best to sub-divide the speed-time curve into its different characteristic parts for further analysis.

Speed-time curves consist of the following parts:

1. Acceleration curve
2. Uniform velocity curve
3. Retardation curve

All the three portions of a speed-time curve, when taken in conjunction with one another, as above enumerated, constitute a "run curve", as they represent all the changes that take place in the speed of a train from the time it starts until it stops. Several "run curves" occurring successively constitute what we will call a "trip curve".

In Fig. 23, page 111, two typical types of speed-time curves are presented, viz: the "run curves" OABCY and OADEFGZ.

In the first named "run curve", that is, the curve OABCY, there are displayed the three distinct fundamental parts of a speed-time curve. The part OAB is the "acceleration curve", and is descriptive of that portion of time at which power is

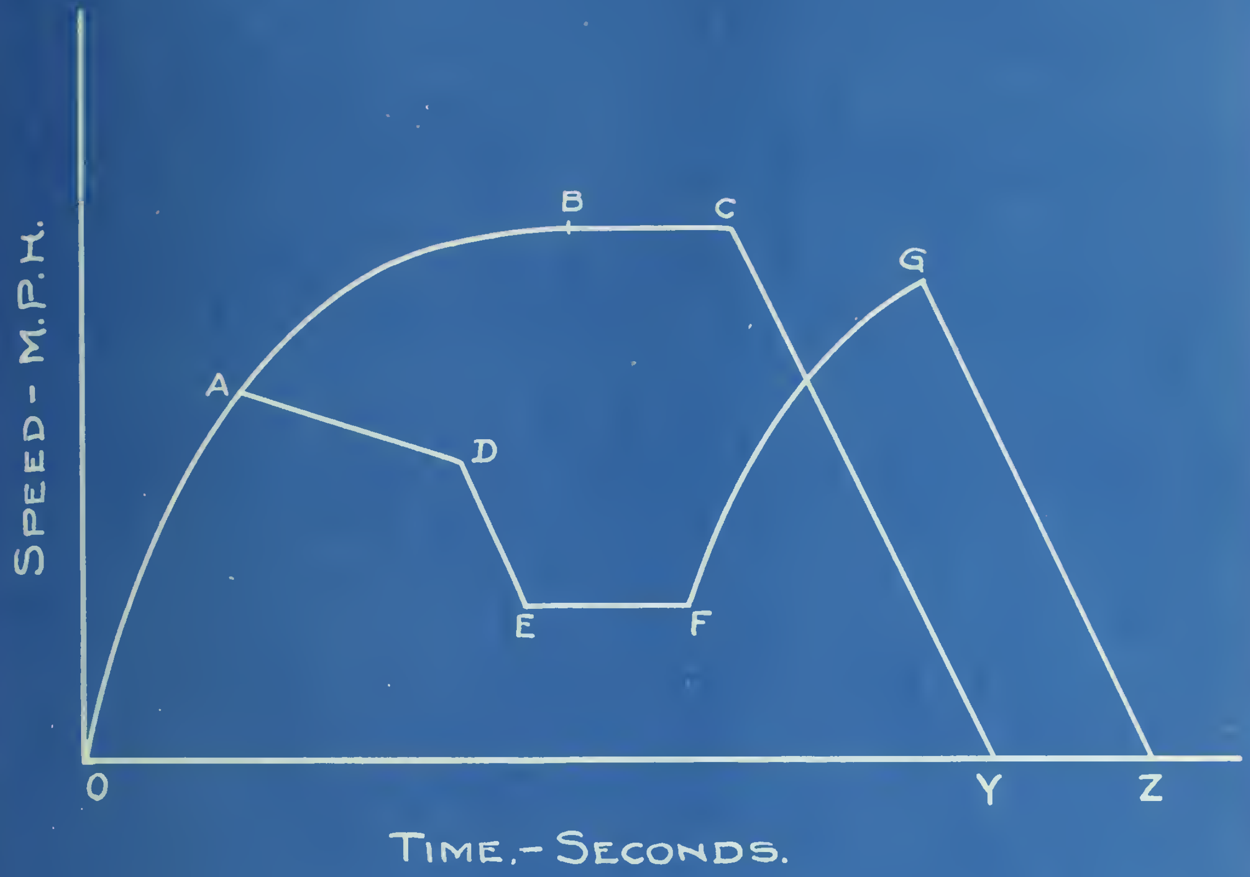

FIG. 23. SPEED-TIME CURVE.

being applied to a train for increasing the speed. At point "B" maximum speed has been reached, which indicates that the tractive effort produced by the locomotive just equals the resistance of the train. The part BC of the "run curve" OABCY is parallel to the time axis OY as it is a uniform velocity curve. The part CY of the same "run curve" is the retardation curve, where the speed is purposely decreased by brake-shoe friction.

In the second named "run curve", viz: the curve OADEFGZ, are the speed-time curves OA and FG, which are representative acceleration curves. At the points A and G in each curve, the power has been cut off before the acceleration became zero, or before a maximum possible speed was attained. In this case, the power has been applied twice to the train during one run. The speed-time curves ADE and GZ are both retardation curves. The portion AD of the retardation curve ADE is called a "drifting curve", and is used to designate that portion of a retardation curve where the rate of retardation is relatively small, and is caused solely by that opposing force known as train resistance. The portion DE of the curve ADE is similar in all respects to the curve GZ, both of which are retardation curves, where the rate of retardation is relatively large, as is produced by braking.

The curve EF is similar to the curve BC, both of which are uniform velocity curves. In the curve EF, the constant

low velocity could be ascribed to such operating conditions as track curvature, slow orders, etc.

In general, the "run curve" OAEFGZ is more representative of actual practice, as the speed is caused to diminish and increase alternately throughout different points along the run.

Further discussions pertaining to the fundamental portions of a speed-time curve follow.

ACCELERATION CURVES.

1. Acceleration of Steam Trains.

The term "acceleration" is used to express the rate of increase in velocity. This term, when used in this paper, whether represented in a numerical or graphical form, will apply to the time rate of change of velocity in steam train practice.

The slope of the acceleration curve at any point may be taken as a definite measure of the time rate of change of velocity at the selected instant of time. For instance, in Fig. 24 where the curve AC is a representative acceleration curve, we have the following analysis:

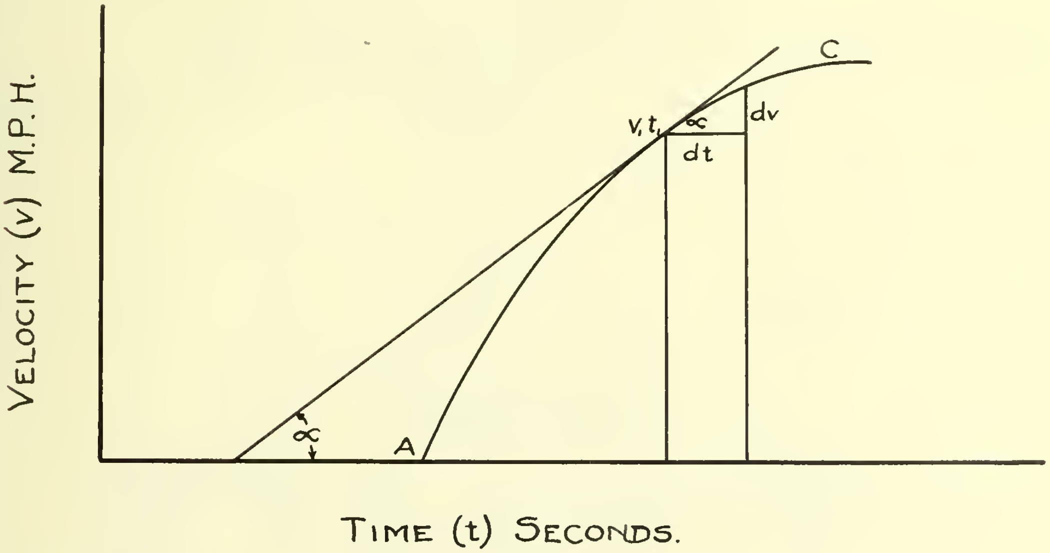

Figure 24.

Let v = velocity of train,

or v = rate at which distance is changing,

then $v = \frac{ds}{dt}$ (31)

and if a = rate at which velocity is changing,

then $a = \frac{dv}{dt}$ (32)

Let $v = f(t)$ be the equation of any acceleration curve.

then $\frac{dv}{dt} = \tan.\alpha$ = slope of curve at any point. (33)

And $\left(\frac{dv}{dt}\right)_{\substack{v=v_1 \\ t=t_1}}$ = slope of curve at point v_1 t_1 (34)

At any point where the curve or tangent to the curve is parallel to the time axis,

$$\alpha = 0$$

therefore $$\frac{dv}{dt} = 0$$

and from equation 32 the acceleration is zero.

At such points where the curve or tangent to the curve is perpendicular to the time axis,

$$\alpha = \infty$$

therefore $$\frac{dv}{dt} = \infty$$

and from equation 32 the acceleration is infinite.

At any other point on the curve,

$$\alpha = \text{an acute angle},$$

therefore $$\frac{dv}{dt} = a, \text{ a positive number},$$

and from equation 32 the acceleration is definitely measured, and is equal to a.

From the above analysis, an acceleration curve may be defined as that portion of a speed-time curve where the differential coefficient is positive, which must necessarily mean that the speed is increasing, corresponding to the time when power is applied to a train to increase that speed.

The logical and most reasonable step in the exposition of the acceleration curve is to show how to obtain it, either in the form of an equation, or by several sets of coordinates, through which a smooth curve can be passed. The latter method, of actually finding the several sets of coordinates, will be explained, as it seems to the writer to be the most practicable and time-saving operation in the solution of any acceleration curve; and should it be deemed expedient to plot the curve, the operation would be simple, as the coordinates of the several points along the curve would be at hand.

Acceleration, as heretofore defined, is caused by a resultant force acting on that body which is accelerated. This resultant force, F, is the algebraic sum of all these forces. This may be stated in the form of an equation, but for reasons of simplicity and as a labor saving device in calculation, it is better to have the different symbols represent force expressed in pounds per ton weight. In such form, the equation becomes,

$$f = t - r \pm g - c \qquad (35)$$

in which

f = force available for acceleration, pounds per ton.

t = force due to tractive effort of the locomotive, pounds per ton.

r = force due to train resistance, pounds per ton.

g = force due to grades, pounds per ton.
(The sign is positive on down grades, and negative on up grades).

c = force due to track curvature, pounds per ton.

The acceleration of any train may be derived from a fundamental law of mechanics, which is

$$f = m\,a.$$

where f = force applied in pounds to produce acceleration

m = mass of body in pounds.

a = acceleration in feet per second per second.

Also, for a weight of one ton

$$a = \frac{f}{m} = \frac{f}{\frac{2000}{32.2}} = \frac{32.2 \times f}{2000} \qquad (36)$$

Now to change the symbol a from feet per second per second to A, the symbol for acceleration in miles per hour per second, we have

$$A = \frac{3600}{5280} \times a = .682 \times a \qquad (37)$$

The resultant force f in formula 35 must be considered as made up of two forces f' and f", in which f' is the force required to overcome the inertia of the train due to

motion of translation, and $\underline{f}''$ is the force required to overcome the inertia of the rotating parts, hence

$$\underline{f} = \underline{f}' + \underline{f}'' \qquad (38)$$

and as a matter of convention, the force $\underline{f}''$ is usually given as a percentage of $\underline{f}'$, as:

Steam locomotive and 8 wheel cars	3 per cent
Steam locomotive and 12 wheel cars . . .	5.5 per cent

Substitute in formula 36 the values of formulae 35, 37 and 38 to get the effective acceleration in miles per hour per second, we have

$$A = \frac{32.2 \text{ x } f \text{ x } .682}{2000 \text{ x } 1.03} \text{ for 8 wheel cars}$$

$$= 0.01065 \; f = 0.01065 \; (t - r \pm g - c) \qquad (39)$$

$$A = \frac{32.2 \text{ x } f \text{ x } .682}{2000 \text{ x } 1.055} \text{ for 12 wheel cars}$$

$$= 0.0104 \; f = 0.0104 \; (t - r \pm g - c) \qquad (40)$$

where

A = acceleration in miles per hour per second.

f = force available for acceleration, pounds per ton, as derived in equation 35.

USE OF ACCELERATION CURVE.

After the acceleration of a train at any instant has been determined, as by the application of formula 39 or 40, whereby the variation of velocity and time are ascertained,

the distance traveled in any length of time may be determined from that data by a process which is fully explained as follows:

Conceive any general acceleration curve where the velocity is expressed in miles per hour and the time in seconds, as in Fig. 25, the following analysis is considered as general in its application.

Let the curve ON in Fig. 25 be the acceleration curve, and t the elapsed time for changing the velocity from v_1 to v_2; to determine what distance s has been traversed by the train in the time t:

From the curve the average increase in velocity during an increment of time dt is equal to $\frac{1}{2}dv$, therefore the velocity at any time (t_1) is $(v_1 + \frac{1}{2} dv)$, and the distance ds traversed in time dt is equal to $(v_1 + \frac{1}{2}dv)dt$, which is a general case where the term v may be variable. This relation expressed in the form of an equation is as follows:

$$ds = (v_1 + \frac{1}{2}dv)dt \tag{41}$$

Since dv is already infinitesimal, the constant $\frac{1}{2}$ is dropped, and equation 41 changed to the following form and integrated,

$$ds = vdt + dvdt$$

$$\int ds = S = \int (vdt + dvdt)$$

$$= vt + t\int dv \tag{42}$$

The term dv is a positive quantity when the speed increases above v_1 as shown in Fig. 25, therefore

$$S = t(v_1 + \int_{v_1}^{v_2} dv) \tag{43}$$

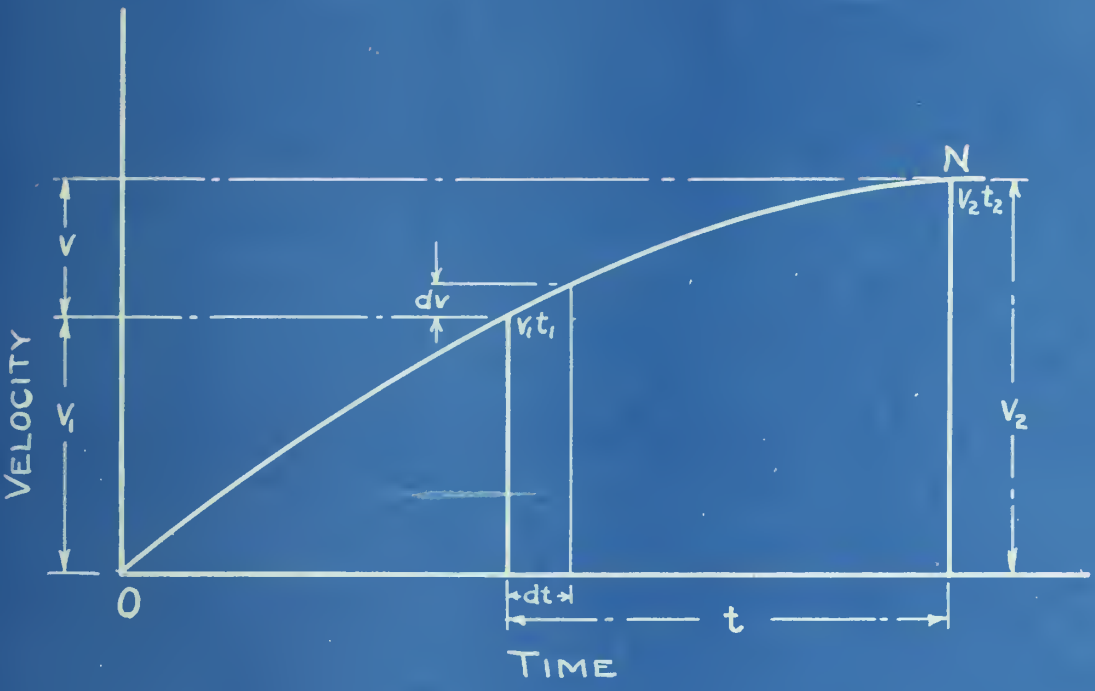

FIG. 25.

where all the quantities are in the same system of units. If the English system is used, then t is given in seconds, and v in feet per second, making the distance S in feet. If v is expressed in miles per hour and t in seconds, and S in feet, it is necessary to employ a reduction constant, determined as follows:

In each mile there are 5280 feet, and in each hour 60 x 60 = 3600 seconds. A speed of 1 mile per hour is then 1.466 feet per second. Each velocity expressed in miles per hour should therefore be multiplied by the constant 1.466 before substituting in equation 43.

When it is desirable to make a mechanical integration by means of a planimeter reading in square inches, a further constant must be employed. Assume the scale of ordinates to be

$$y(\text{M.P.H.}) = 1 \text{ inch}$$

and of abscissae

$$x(\text{seconds}) = 1 \text{ inch}$$

then the area of one square inch is $x(1.466y)$ feet. The total elapsed distance is then

$$S = 1.466\, xyA \tag{44}$$

where A is the area in square inches included between the limits of time and velocity for which the curve is to be integrated.

UNIFORM VELOCITY CURVES.

Uniform Velocity of Steam Trains.

Uniform velocity implies that a moving body traverses equal distances in equal units of time, consequently we have,

$$v = \frac{s}{t}$$

where v = uniform or constant velocity

s = space traversed

t = time

in the same system of units.

Since the velocity is constant, the velocity curve is parallel to the time axis, therefore the angle formed by a tangent to the curve is equal to zero, and from equation 33,

$$\frac{dv}{dt} = 0$$

which indicates no acceleration.

Uniform velocity in the movement of steam railway trains is unusual. Its infrequency is most probably due to the characteristics of steam railway service, which permits only two possible cases for such an occurrence. The first condition of this kind is well represented by the curve BC in Fig. 23 in this appendix, where zero acceleration has been reached and the force of the engine is exactly balanced by the resultant forces of resistance. The second condition is represented by the curve EF in the same figure, where the force of the engine is balanced by the resistances, but not at the maximum speed.

RETARDATION CURVES.

Retardation of Steam Trains.

The speed-time curve, as heretofore stated, is arbitrarily divided into three prevailing divisions, namely, the time for acceleration, the time for nominally constant speed, and the time for retardation. The last of these three divisions, i.e., the time for retardation, when shown graphically with respect to speed, constitutes that portion of a speed-time curve which is called the "retardation curve". The slope of the "retardation curve" at any point may be taken as a definite measure of the time rate of change of velocity at the selected instant of time. For instance, in Fig. 26 where the curve BD is any representative retardation curve, we apply the same analysis as in the case of the acceleration curve, viz.:

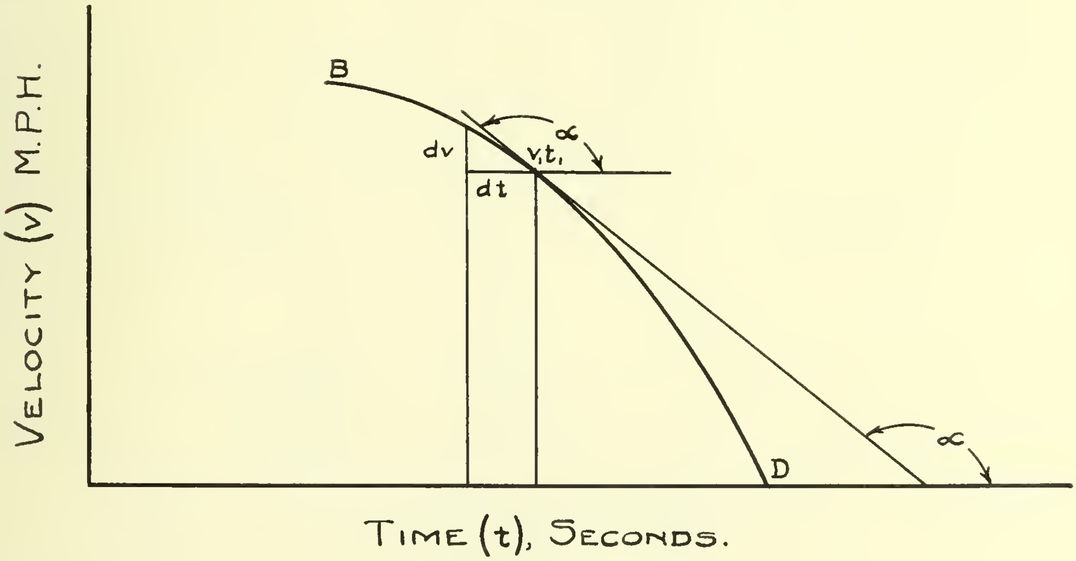

Figure 26.

By equation 33

$$\frac{dv}{dt} = \tan.\alpha = \text{slope at any point}$$

but in this case,

$$\alpha = \text{an obtuse angle}$$

therefore

$$\frac{dv}{dt} = -\underline{a}, \text{ a negative number;}$$

and from equation 32 the acceleration is definitely measured and is equal to $-\underline{a}$.

From this analysis, the retardation curve may be defined as that portion of a speed-time curve where the differential coefficient is negative.

This curve is further divided into two parts, one part known as a "drifting curve" and the other as a "braking curve" as explained in Fig. 23, page 111. Either form of a retardation curve may be treated in precisely the same manner as the acceleration curve. In fact, the same equations will apply to both classes of curves, the difference being expressed by their signs. This distinction means that the retarding force is considered as acting in the line of motion but opposed to it.

Retardation is caused by a resultant force acting on a body and opposing its motion. This resultant force, F, is the algebraic sum of all the forces acting. Therefore, equation 35, which is presented on page 116, is a general equation representing such a condition. The equation,

expressed in pounds per ton, is

$$f = t - r \pm g - c$$

If the term t is not acting during retardation, it disappears from the equation. And if the brakes are not used during retardation, the following equation is representative of the retarding force available during "drifting", as

$$-f = -r \pm g - c \qquad (45)$$

where

f = force available for retardation, pounds per ton.

r = force due to internal friction, flange friction, air resistance, etc., known as train resistance.

g = force due to grades, pounds per ton.
(The sign is positive on down grades and negative on up grades).

c = force absorbed by track curvature, pounds per ton.

This equation represents that part of train motion where the propelling force is due to the stored kinetic energy previously absorbed by the train. Under these circumstances, the train is said to be "drifting", and will continue to do so, with the speed gradually decreasing, due to the absorption of stored energy by those resistances represented by equation 45, until the train comes to rest.

If the brakes are used to increase the rate of retardation, then the graphical exhibition of the variation of velocity and time forms a curve called the "braking curve", which depicts the results of all the factors tending to change

the velocity of the train. This additional retarding force is inserted into the original equation, where it takes the negative sign and changes equation 45 to the following:

$$-f = -b - r \pm g - c \qquad (46)$$

which is the elementary formula for retardation when the brakes are used. Evidently the slope of the "braking curve" not only depends on the value of the brake-shoe friction (b), but also on the train resistance (r), per cent of grade (g), and track curvature (c). With the exception of the term b, the determination of all the other terms is fully explained under the appendix treating of "Train Resistance".

The determination of values for the term b which pertains to steam train braking, is given in the succeeding pages.

The time required for retardation is becoming of more importance and of greater significance as the weights and speeds of trains increase. Where stops are frequent, it is feasible to decrease the running time of steam trains by adequate braking.

The method employed for braking is by no means ideal. Ideal braking would constitute a braking force that opposes the motion of the train and acts at its center of gravity, which would stop the train in the least possible time without damage to the equipment or discomfort to the passengers. In practice, ideal braking is impossible; instead, we have the force applied at the wheel treads which produces brake-shoe friction. This results in a force that opposes their tendency to revolve and is

the principal retarding force.

The energy of the train in motion may be dissipated in the brake-shoes, due to the relative motion between the train and the track, by the medium of the adhesion between the wheel and rail. Therefore, a proper braking force should be equal in magnitude to the adhesion between the wheels and the rail when the wheels are rolling thereon. In practice, however, such a braking force is not practicable except at low speeds and where the train has a constant weight, unless there is adopted some form of a variable load brake.

The first scientific research to determine the value of brake-shoe friction between cast-iron brake-shoes and steel wheels of moving trains, was performed on the London, Brighton and South Coast Railway in 1878 by Sir Douglas Galton and Mr. George Westinghouse. The results of their tests may be found in the proceedings of the I. M. E. of England.

In these tests, the average pressures between shoe and wheel varied from 30 to 90 pounds per square inch, although the experiment included tests with shoe pressures as high as 200 pounds per square inch. The high shoe pressures resulted in a low coefficient of friction, while the lower shoe pressures have correspondingly higher coefficients of friction.

The following equation represents the variation of the mean coefficient of friction with the velocity of the train, as:

$$n = \frac{0.326}{1+0.03532\,V} \qquad (47)$$

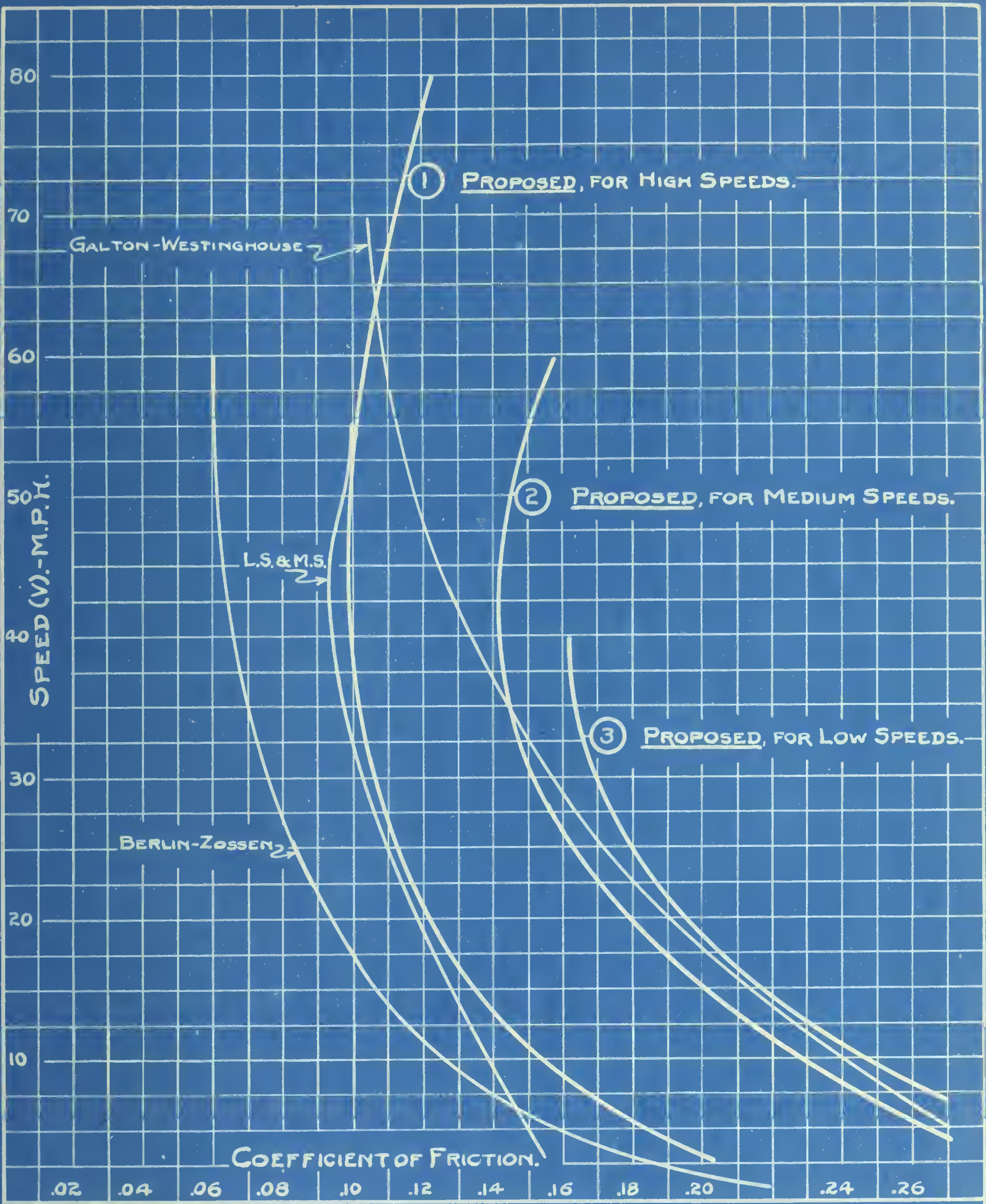

FIG. 27.

BRAKE-SHOE FRICTION CURVES.

where

n = mean coefficient of friction

V = velocity in miles per hour.

The graphical representation of equation 47 is exhibited in the curve marked Galton-Westinghouse in Fig. 27 on page 128 in this appendix. The curve depicts a regular decrease in the coefficient of friction as the speed increases until 70 miles per hour is reached, after which the frictional qualities decrease less rapidly. In these tests, it must be kept in mind that the coefficients of friction as represented by equation 47, are the average of those observed at the beginning of the brake application only. No doubt the various brake-shoe pressures are mainly responsible for the variation of the coefficient of friction, since the pressures varied from 30 to 200 pounds per square inch, and no distinction was made between the frictional values which should accompany the corresponding pressures, from which they never should have been separated.

From our present knowledge of brake-shoe friction between cast-iron shoes and steel wheels, we know that it varies not only with speed, but also with pressure and with the time of contact between the shoe and the wheel tread.

The results of the Berlin-Zossen tests are also shown as a curve in Fig. 27, of which the equation is

$$n = \frac{0.186}{1 + 0.0476\,V} \qquad (48)$$

where

n = coefficient of friction

V = Speed in miles per hour.

Here again there is a certain indefiniteness which precludes the use of such results in modern steam train service.

Probably the most reliable source of information on the subject of brake-shoe friction is the Proceedings of the Master Car Builders Association of America. But even here, the data collected on the subject of brake-shoe friction is mostly descriptive of the average shoe friction throughout a stop instead of the actual shoe friction at the different speeds during a stop. It must be borne in mind that in the predetermination of a braking curve where the speeds at different instants of time are the data desired, it is necessary to obtain the force producing this retardation at successive instants of time, and this force, which we call the braking force, is principally dependent on the coefficient of friction between the wheel and the shoe.

More extended experiments to determine the value and extent of brake-shoe friction were performed on passenger trains in the year 1910 on the L.S.& M.S. R.R. at Milbury Junction, Ohio. These tests, conducted under the direction of the L.S. & M.S. R.R. and P. R.R., form a treatise which is one of the most exhaustive in print on the practicability of high brake-shoe pressures, the effectiveness of different braking equipments, the variation of brake-shoe friction, and

many other important points connected with the general subject.

In these above noted tests, the important change was effected of determining the coefficient of brake-shoe friction at different speeds and at different pressures (which means by the use of different air brake equipments); not by acquiring data covering the initial coefficient of friction at different speeds, but by continuously recording the coefficient of friction and speed throughout a specified stop, thus making it truly representative of the action taking place between the steel wheel-tread and the cast-iron brake-shoe during such a stop.

Several representative stops have been selected from which the coefficients of brake-shoe friction are derived for 8 wheel passenger cars. These cars were equipped with Westinghouse high speed brake equipment designed to give, with an 8 inch piston travel and 110 pounds brake pipe pressure, a maximum emergency pressure of 80 pounds, which gradually blows down to 60 pounds toward the end of the stop. The results are shown in Fig. 27, page 128 by a mean curve (marked L.S. & M.S.) which takes the form of a cubical parabola. If represented in the form of an equation, we have:

$$n = 0.1588 - 0.00218\ V - 0.0000114\ V^2 + 0.000000618\ V^3 \quad (49)$$

where

n = coefficient of friction between steel wheel and cast-iron brake shoe,

V = velocity of train in m.p.h.

The form of the above equation is entirely new when used to depict the variation in the coefficient of brake-shoe friction with speed.

The experiments from which equation 49 is derived, are all from runs in which the initial speeds are nominally 60 miles per hour, therefore the plotted points of maximum speed are slightly lower or are approximately 55 miles per hour. To the writer, it seems that particular attention should be called to the fact that at speeds of 35 and 50 miles per hour, the coefficient of friction is the same, and at a speed of 42 miles per hour, the coefficient of friction is less than at either of the above speeds. From an analysis of such curves, it seems that the apparent hook or drop in the curve is due to the immense heat generated during the early part of the stop, where the change in the speed is relatively small, resulting in melting of the face of the shoe, which, in turn, acts as a lubricant. This is later overcome by a tendency of the coefficient of friction to increase, due to the decrease in speed and pressure.

Accepting the above conclusions, the question is still open as to whether this hook or drop in the coefficient of friction is invariable with respect to the initial speed at brake application. To the writer, it seems that this hook or sudden decrease in the coefficient of friction, is a function of the initial speed at which the brake application

is made, provided the brake-shoe pressure is constant.

In the absence of more complete experimental data, brake-shoe tests were conducted at the University of Illinois in order that more definite conclusions could be drawn as to the variations of brake-shoe friction with speed and pressure.

The tests were conducted upon the brake-shoe testing machine of the University of Illinois, which is built in accordance with the specifications of the Master Car Builders Association and has a fly wheel, the energy of which is equivalent to a load of 12,500 pounds on the car wheel. The kinetic energy of the fly wheel in terms of the velocity at the rim of a 33 inch car wheel, is expressed by the equation:

$$K.\ E. = 412\ V^2$$

in which

K. E. = kinetic energy of the fly-wheel in foot-pounds.

V. = velocity at the rim of the car wheel in miles per hour.

If we compare this with the kinetic energy of translation per wheel of a 12 wheel all steel Pullman car weighing 145,000 pounds, we find that the energy per car wheel involved in either case is the same, as;

$$K.\ E. = \frac{1}{2} M\ v^2$$

$$= \frac{1 \times 145000\ v^2}{2 \times 12 \times 32.2}$$

$$= 187.5 v^2 \text{ where } v \text{ is in f.p.s.}$$

$= 187.5 \times (1.466)^2 V^2 = \underline{406\ V^2}$; where V is in miles per hour.

In this calculation, the kinetic energy of rotation of the car wheel has been neglected, as no account is taken of it in the formula for kinetic energy of the fly-wheel of the brake-shoe machine.

The close correspondence between the kinetic energy of the fly-wheel and the kinetic energy dissipated per car wheel in actual service-stops from the same speed, makes it reasonable to suppose that the coefficients of friction obtained from the testing machine will not vary greatly from those obtained in service.

The methods of making the tests were two: first, by applying pressure by means of weights; and second, by applying pressure by means of compressed air operating a brake cylinder, in order to determine if there was any appreciable difference in the coefficient of friction obtained, but so far as could be ascertained, the action was the same in both cases*, although the brake cylinder has the advantage over the weights in being free from vibration, thereby making it possible to accurately investigate the coefficient of friction early in the stop. After each application the shoes were cooled to approximately room temperature.

In Fig. 28 there is produced an actual card taken from the testing machine, which was obtained by making the

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*See "Tests of Brake-shoes" by A. F. Stuebing, Univ. of Ill. 1911.

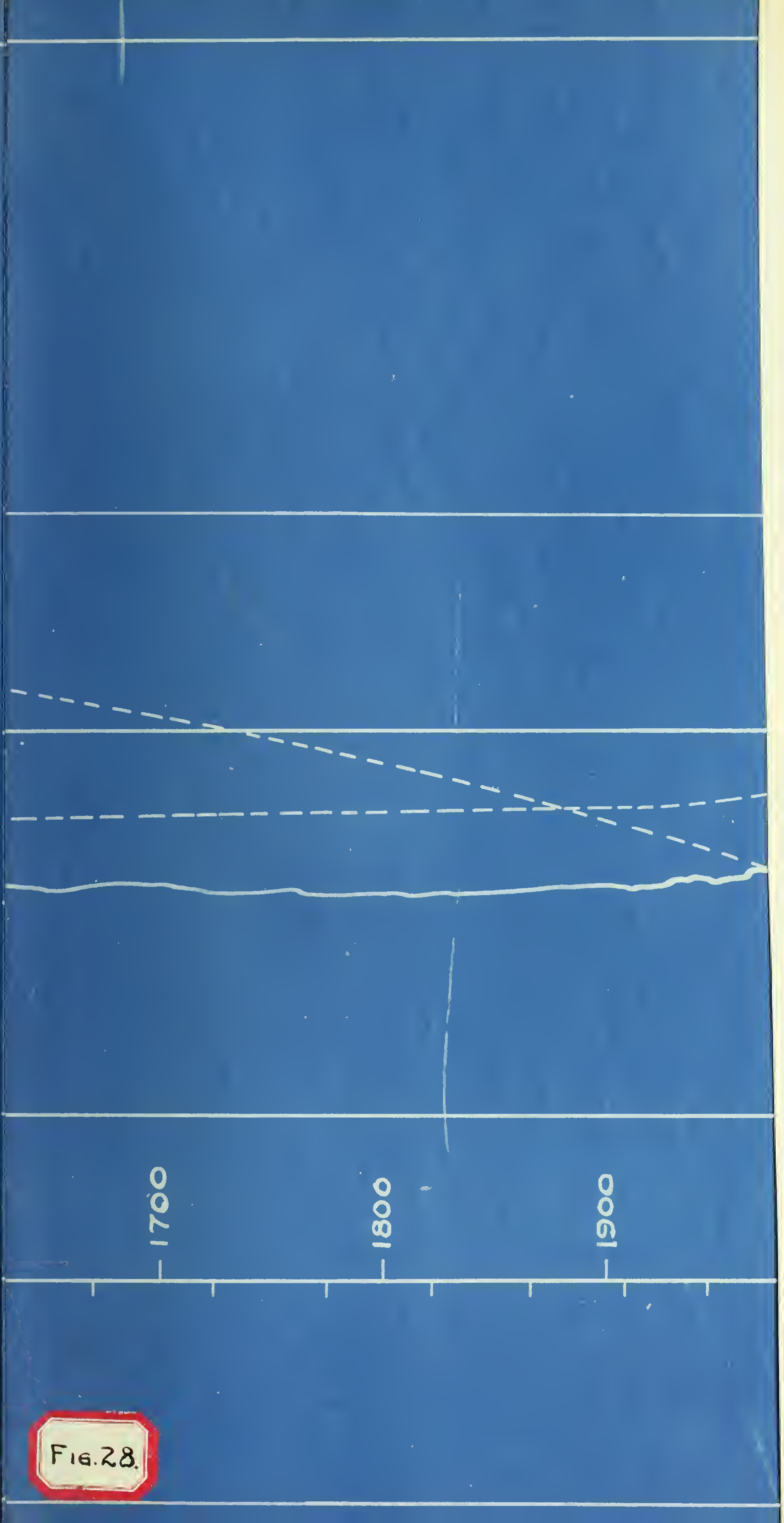

Fig. 28.

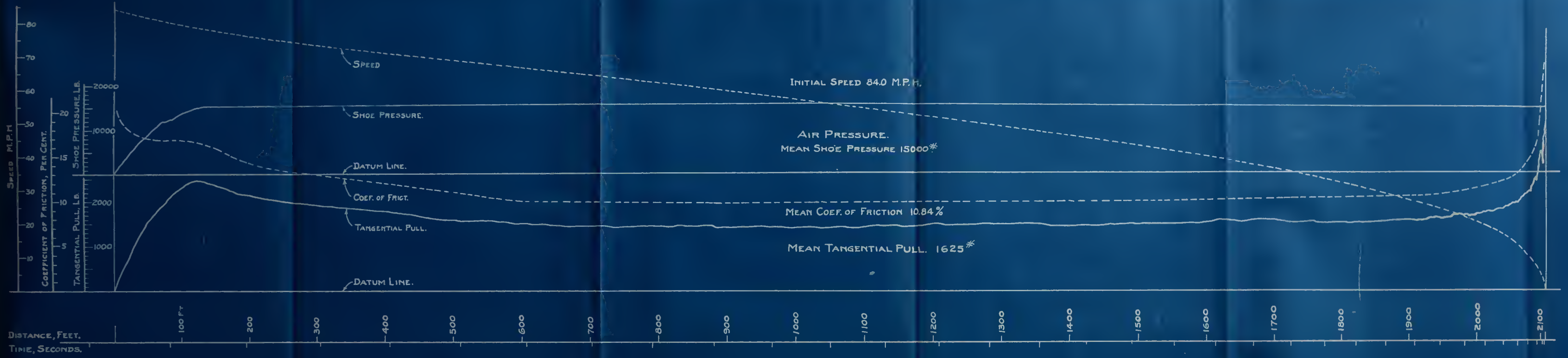

Fig. 28. Typical Card from Brake-Shoe Testing Machine

Fig. 28

application with air. The solid lines shown on this card are made by the machine; they are:

1. Tangential pull, pounds (1 inch ordinate = 1000 lbs. pull).
2. Shoe pressure, pounds (1 inch ordinate = 10,000 lbs.).
3. Time, seconds (interval between off-sets = 1 sec.).
4. Distance, feet. (The gearing of the drum by which the card is driven is such that one inch of paper travel corresponds to 65.06 feet of car travel).

The speed and coefficient of friction curves are derived from the data supplied by the cards and are shown by the dotted lines.

In all, some 50 tests have been analyzed for the variation of coefficient of brake-shoe friction with speed between a steel-tired car wheel and cast-iron brake-shoe with expanded steel inserts. The results have been divided into three classes, namely:

1. Stops from high speeds (80 miles per hour).
2. Stops from medium speeds (60 miles per hour).
3. Stops from low speeds (40 miles per hour).

The speeds from which the stops are made may be taken as a measure of the brake-shoe pressure; that is, the shoe pressure is assumed to be a function of the speed, for, in stopping from a speed of 80 miles per hour, a shoe pressure of 16000 or 18000 pounds would be employed; if the stop was from 60 miles per hour, then a shoe pressure of 12000 pounds would be sufficient; and if

the stop was from 40 miles per hour, then a shoe pressure of 6000 pounds would be representative of conditions, provided that in each case emergency application is assumed.

In Fig. 28 the proposed curves for the average coefficient of friction are shown under the above assumed conditions, which are:

Proposed curve No. 1.

Results of tests made by making applications from an initial speed of nominally 80 miles per hour, and a shoe pressure varying from 16000 to 18000 pounds.

Proposed curve No. 2.

Results of tests made by making applications from an initial speed of nominally 60 miles per hour, and a shoe pressure varying from 10000 to 12000 pounds. This pressure represents the maximum used in full service applications with the ordinary passenger equipment.

Proposed curve No. 3.

Results of tests made by making applications from an initial speed of nominally 40 miles per hour, and a shoe pressure of approximately 6800 pounds. This pressure represents the average used in service applications with the ordinary passenger equipment for slow speed stops, and the maximum used in full service applications with the usual freight equipments.

During some of the high speed, high pressure tests, the shoe was noticed to be bearing unevenly upon the wheel tread as

was shown by its unequal heating.

In every case, the shoe had a contour to fit the wheel tread when cold, but as the shoe became heated there was a decided tendency for it to flatten out, resulting in the ends of the shoe breaking contact with the wheel tread. This was probably caused by greater generation of heat toward the center of the shoe, which happened in some cases shortly after the application had been made, and was evident from a red glow which first appeared distributed over the shoe and later concentrated itself toward the center. Such action probably accounts for the irregularities in the results of tests performed under apparently identical conditions.

The results of these tests as shown by the three curves in Fig. 28 do not confirm the old theory that the coefficient of friction due to a given brake-shoe pressure increases as the speed diminishes. But, on the contrary, under modern conditions of high speed and heavy brake-shoe pressures, the rapid destruction of the brake-shoes which tends to lubricate the surfaces in contact, causes a marked reduction in the coefficient of friction which more than neutralizes the effect of dimishing speed, until a speed is reached where the rate of dissipation of energy is small enough to overcome this tendency.

The proposed curves in Fig. 28 are to be used in this article for determining the retarding force due to the

action of the brakes. Proposed curve No. 1 is to be used for trains where the initial speed ranges from 60 to 80 miles per hour; proposed curve No. 2 is to be used for trains where the initial speed ranges from 40 to 60 miles per hour; and proposed curve No. 3 is to be used for initial speeds below 40 miles per hour.

Now, suppose a brake-shoe to be applied to a wheel with a pressure which is 0.9 of the load carried by that wheel. Then the load carried by that wheel multiplied by 0.9 multiplied by the coefficient of kinetic friction between brake-shoe and wheel tread, gives the retarding force at that speed tending to stop rotation.

This retarding force is represented by the term $\underline{-b}$ in equation $\underline{15}$, which is the retarding force in pounds per ton weight, and is derived as follows:

Let A = a factor of retardation.

W = loaded weight of train in tons, excluding locomotive and tender.

w = light weight of train in tons, excluding locomotive and tender,

n = coefficient of brake-shoe friction,

p = per cent of braking power,

= 90% of light weight of car for passenger equipment,

= 70% of light weight of car for freight equipment,

Then

$$-b = -(A \times \frac{w}{W} \times n \times p)2000 \qquad (50)$$

All the terms, with the exception of term A in equation 50 are self-explanatory. Term A is inserted in this equation to account for the force due to the unbraked locomotive effort. It is a well known fact that locomotives are not braked as high per ton weight as are passenger cars. Hence, the draw-bar pull during retardation is often very great, a fact which can be verified by many tests, among which are those performed on the New York Central Lines in 1902 by Bion J. Arnold, and in those performed on the Lake Shore and Michigan Southern Railroad in 1910.

Previous tests seem to indicate that the effectiveness per ton weight of brakes on locomotive and tender is approximately 75% of that on cars. Then, if we let

A = factor of retardation,
W_t = weight of train in tons,
W_l = weight of locomotive and tender in tons,
W_c = weight of cars in tons,
P_t = retarding force acting on train,
P_l = retarding force acting on locomotive and tender,
P_c = retarding force acting on cars.

Then

$$W_t = W_l + W_c$$

Also

$$P_t = P_l + P_c \quad \text{and} \quad \frac{P_t}{W_t} = \frac{P_l}{W_l} + \frac{P_c}{W_c}$$

And by assumption,

$$\frac{\frac{P_1}{W_1}}{\frac{P_c}{W_c}} = .75 \qquad\qquad \frac{P_1}{W_1} = .75\frac{P_c}{W_c}$$

$$A = \frac{P_t}{W_t} = \frac{\left(\frac{P_1}{W_1} \times W_1\right) + \left(\frac{P_c}{W_c} \times W_c\right)}{W_t}$$

Since we want $\frac{P_1}{W_1}$ in terms of $\frac{P_c}{W_c}$, we have

$$A = \frac{\left(\frac{.75\ P_c}{W_c} \times W_1\right) + \left(\frac{P_c}{W_c} \times W_c\right)}{W_t}$$

$$= \frac{.75\left(\frac{P_c}{W_c}\right) \times W_1 + \left(\frac{P_c}{W_c}\right) \times W_c}{W_t}$$

Now, since the term $\frac{P_c}{W_c}$ is in terms of $\frac{P_t}{W_t}$, its meaning is understood and may, therefore, be dropped, which reduces the equation to the following form, viz.:

$$A = \frac{.75\ W_1 + W_c}{W_t} \tag{51}$$

As an example of the application of equation 51, let us assume two trains of different weights, as:

	Case 1	Case 2
Weight in tons of locomotive and tender,	100	100
" " " " cars,	600	200
" " " " train,	700	300

The value of A, by formula 51, for case 1, is .964 and for case 2, .917. Therefore, a greater car retarding force will be necessary to stop the train, in the proportion of 1 to .964 for the first case, and in the proportion of 1 to .917 in the second case, than if the lesser braking effort on the locomotive and tender were not considered.

To get the effective negative acceleration in m.p.h.p.s., we have from formula 40,

$$A = .01065\ f$$

but since we are dealing with retardation, the term $-f$ of formula 46 must be substituted for the term f of formula 40, which gives,

$$\begin{aligned} A &= 0.01065\ (-f) \text{ for 8 wheel cars} \\ &= 0.01065\ (-b-r\pm g-c) \qquad (52) \end{aligned}$$

and in like manner,

$$\begin{aligned} A &= 0.0104\ (-f) \text{ for 12 wheel cars} \\ &= 0.0104\ (-b-r\pm g-c) \qquad (53) \end{aligned}$$

These formulae (52) and (53) have been used throughout this article for determining retardation in miles per hour per second.

APPENDIX IV.

PART II.

CALCULATIONS OF
SPEED-TIME CURVES
FOR
STEAM TRAIN SERVICE.

CALCULATIONS OF
SPEED-TIME CURVES
FOR
STEAM TRAIN SERVICE.

It is here intended to exhibit the computed results of acceleration and retardation of the four locomotives heretofore mentioned. Each locomotive is considered as hauling the four trains, namely:

(1) 200 ton Passenger train of 5 coaches;
(2) 600 " " " " 10 " ;
(3) 1000 " Freight " " 45 cars ;
(4) 2000 " " " " 90 " ;

The conditions of the problem are: That the small driver locomotives are not to exceed a speed limit of 60 miles per hour, and that the maximum speed for the large driver locomotives is 80 miles per hour; that the maximum speed for either freight train is 40 miles per hour. These restrictions are made in order that actual service conditions may be more nearly approximated.

Under these conditions, Tables Nos. XIV, XV, XVI, and XVII, shown at the conclusion of this Appendix, have been prepared, which give in detail the various calculations involving acceleration, time, distance, etc. Each of these columns of data bears a number in the tables and a concise explanation of the methods employed to obtain it, is given.

These explanations are as follows:

ACCELERATION.

Column 1. Speed in miles per hour.

Column 2. Available tender draw-bar pull in pounds, 1% up grade, = column 3 - 20(weight of locomotive in tons + 0.7 weight of maximum loaded tender in tons).

Column 3. Available tender draw-bar pull in pounds, level track. This item is the same as is shown in Table VIII in Appendix I, Part II, or, as calculated by equations 1 and 9 in the same appendix.

Column 4. Available tender draw-bar pull in pounds, 1% down grade, = column 3 + 20(weight of locomotive in tons + 0.7 weight of maximum loaded tender in tons).

Column 5. Available tender draw-bar pull per ton of train, pounds, 1% up grade, = column 2 ÷ weight of train in tons.

Column 6. Available tender draw-bar pull per ton of train, pounds, level track, = column 3 ÷ weight of train in tons.

Column 7. Available tender draw-bar pull per ton of train, pounds, 1% down grade, = column 4 ÷ weight of train in tons.

Column 8. Resistance of train, pounds per ton, 1% up grade, = column 9 + 20.

Column 9. Resistance of train, pounds per ton, level track, For passenger trains by equation 28 in Appendix III; for freight trains, by equation 26 in Appendix III on train resistance.

Column 10. Resistance of train, pounds per ton, 1% down grade, = column 9 - 20.

Column 11. Tender draw-bar pull available for acceleration, pounds per ton, 1% up grade, = column 5 - column 8.

Column 12. Tender draw-bar pull available for acceleration, pounds per ton, level track, = column 6 - column 9.

Column 13. Tender draw-bar pull available for acceleration, pounds per ton, 1% down grade, = column 7 - column 10.

Column 14. Acceleration in miles per hour per second, 1% up grade. For 8 wheel cars, by the application of equation 39 in Appendix IV, Part I, on Speed-time curves; for 12 wheel cars, by the application of equation 40 in Appendix IV, Part I, on Speed-time curves.

Column 16. Acceleration in miles per hour per second, 1% down grade. For 8 wheel cars, by the application of equation 39 in Appendix IV, Part I, on Speed-time curves; for 12 wheel cars, by the application of equation 40 in Appendix IV, Part I, on Speed-time curves.

Column 17. Mean acceleration in miles per hour per second, 1% up grade. Mean of two consecutive values in column 14.

Column 18. Mean acceleration in miles per hour per second, level track. Mean of two consecutive values in column 15.

Column 19. Mean acceleration in miles per hour per second, 1% down grade. Mean of two consecutive values in column 16.

Column 20. Time to produce changes of speed as shown in column 1, seconds, 1% up grade. Difference of consecutive values in column 1 ÷ column 17.

Column 21. Total acceleration time, seconds, 1% up grade, = sum of all values in column 20.

Column 22. Time to produce changes of speed as shown in column 1, seconds, level track. Difference of consecutive values in column 1 ÷ column 18.

Column 23. Total acceleration time, seconds, level track, = sum of all values in column 22.

Column 24. Time to produce changes of speed as shown in column 1, seconds, 1% down grade. Difference of consecutive values in column 1 ÷ column 19.

Column 25. Total acceleration time, seconds, 1% down grade, = sum of all values in column 24.

Column 26. Distance traveled to produce changes of speed as shown in column 1, feet, 1% up grade, = (one-half the sum of two consecutive values in column 1) x (1.466 x column 20).

Column 27. Total distance traveled, feet, 1% up grade. Sum of all values in column 26.

Column 28. Distance traveled to produce changes of speed as shown in column 1, feet, level track, = (one-half the sum of two consecutive values in column 1) x (1.466 x column 18).

Column 29. Total distance traveled, feet, level track. Sum of all values in column 28.

Column 30. Distance traveled to produce changes of speed as shown in column 1, feet, 1% down grade, = (one-half the sum of two consecutive values in column 1) x (1.466 x column 19).

Column 31. Total distance traveled, feet, 1% down grade. Sum of all values in column 30.

RETARDATION.

Column 32. Train speed in miles per hour.

Column 33. Retardation in miles per hour per second, 1% up grade. For 8 wheel cars, by the application of equation 52 in Appendix IV, Part I, on Speed-time curves; for 12 wheel cars, by the application of equation 53 in Appendix IV, Part I, on Speed-time curves.

Column 34. Retardation in miles per hour per second, level track. For 8 wheel cars, by the application of equation 52 in Appendix IV, Part I, on Speed-time curves; for 12 wheel cars, by the application of equation 53 in Appendix IV, Part I, on Speed-time curves.

Column 35. Retardation in miles per hour per second, 1% down grade. For 8 wheel cars, by the application of

equation 52 in Appendix IV, Part I, on Speed-time curves; for 12 wheel cars, by the application of equation 53 in Appendix IV, Part I, on speed-time curves.

Column 36. Mean retardation in miles per hour per second, 1% up grade. Mean of two consecutive values in column 33.

Column 37. Mean retardation in miles per hour per second, level track. Mean of two consecutive values in column 34.

Column 38. Mean retardation in miles per hour per second, 1% down grade. Mean of two consecutive values in column 35.

Column 39. Time to produce changes of speed as shown in column 32, seconds, 1% down grade, = difference of consecutive values in column 32 ÷ column 36.

Column 40. Total retardation time, seconds, 1% down grade. Sum of all values in column 39.

Column 41. Time to produce changes in speed as shown in column 32, seconds, level grade, = difference of consecutive values in column 32 ÷ column 37.

Column 42. Total retardation time, seconds, level grade. Sum of all values in column 41.

Column 43. Time to produce changes of speed as shown in column 32, seconds, 1% down grade, = difference of consecutive values in column 32 ÷ column 38.

Column 44. Total retardation time, seconds, 1% down grade. Sum of all values in column 43.

Column 45. Distance traveled to produce changes of speed as shown in column 32, feet, 1% up grade, = (one-half the sum of two consecutive values in column 32) x (1.466 x column 39).

Column 46. Total distance traveled, feet, 1% up grade. Sum of all values in column 45.

Column 47. Distance traveled to produce changes of speed as shown in column 32, feet, level track, = (one-half the sum of two consecutive values in column 32) x (1.466 x column 41).

Column 48. Total distance traveled, feet, level track. Sum of all values in column 47.

Column 49. Distance traveled to produce changes of speed as shown in column 32, feet, 1% down grade, = (one-half the sum of two consecutive values in column 32) x (1.466 x column 43).

Column 50. Total distance traveled, feet, 1% down grade. Sum of all values in column 49.

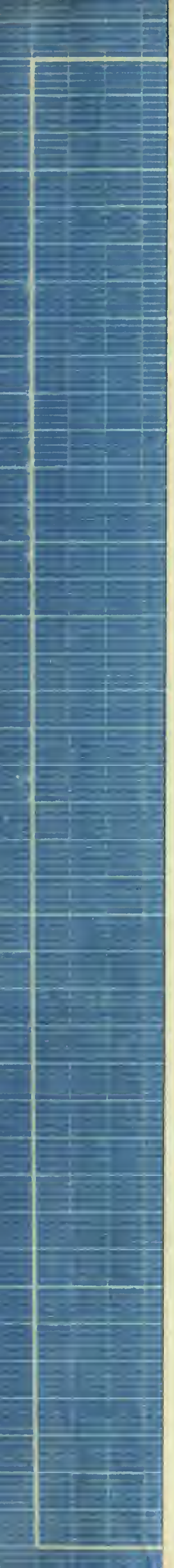

FIG. 29.

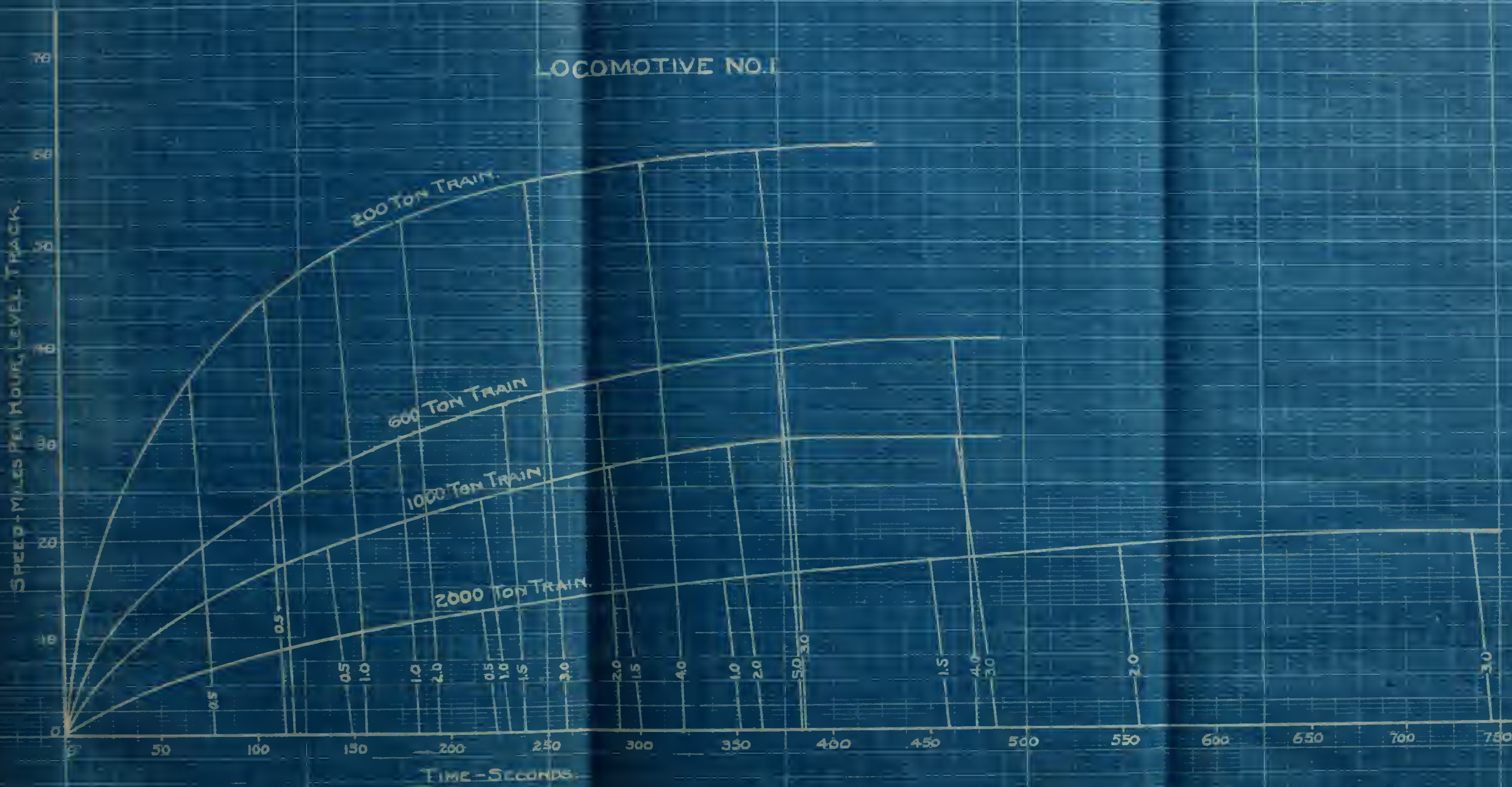

Fig. 29. Speed-Time Curves.

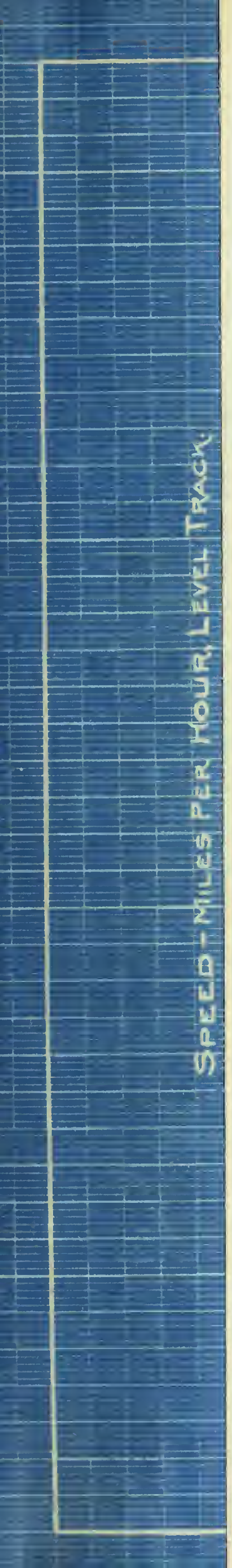

Fig. 30.

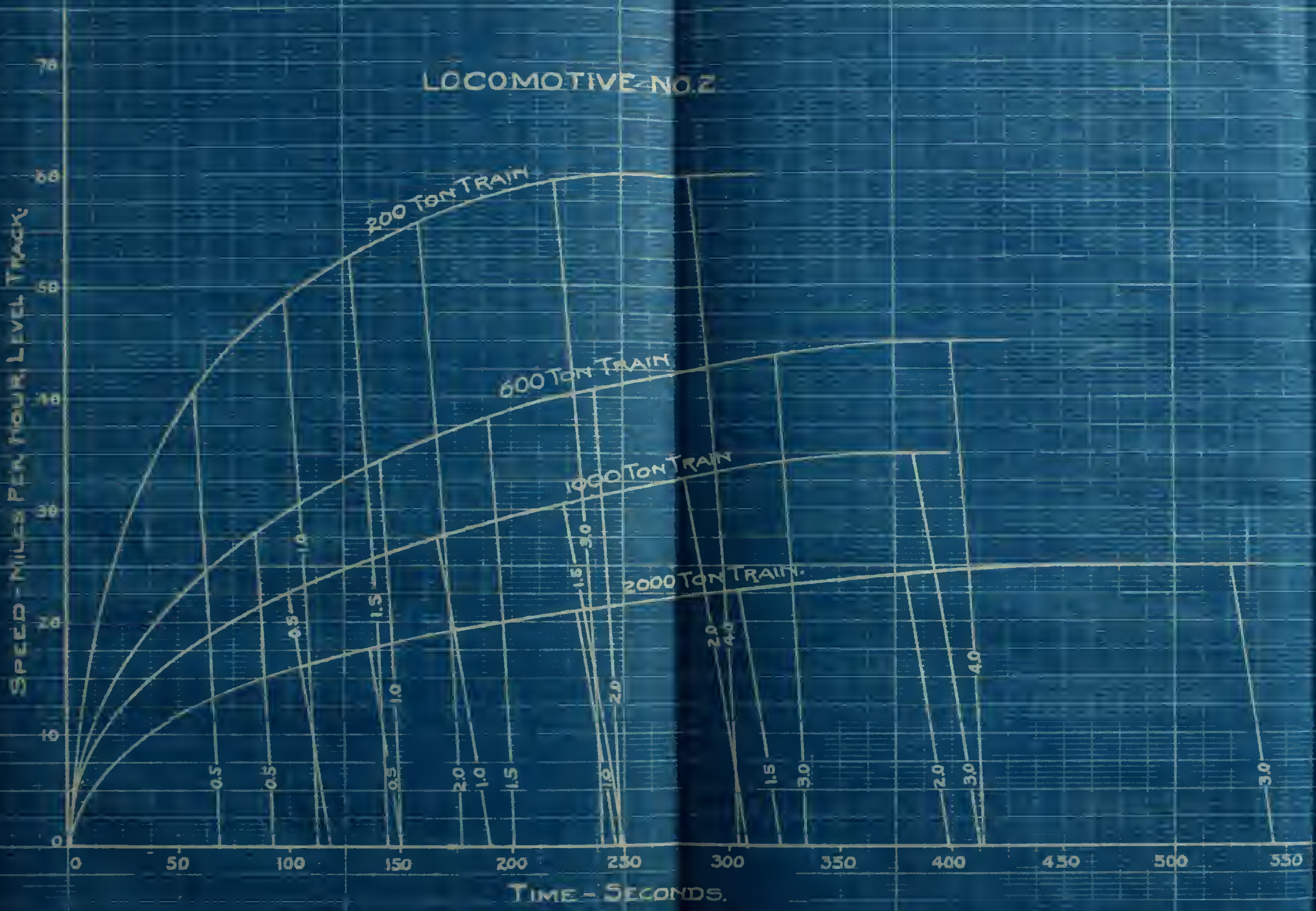

Fig. 30. Speed-Time Curves.

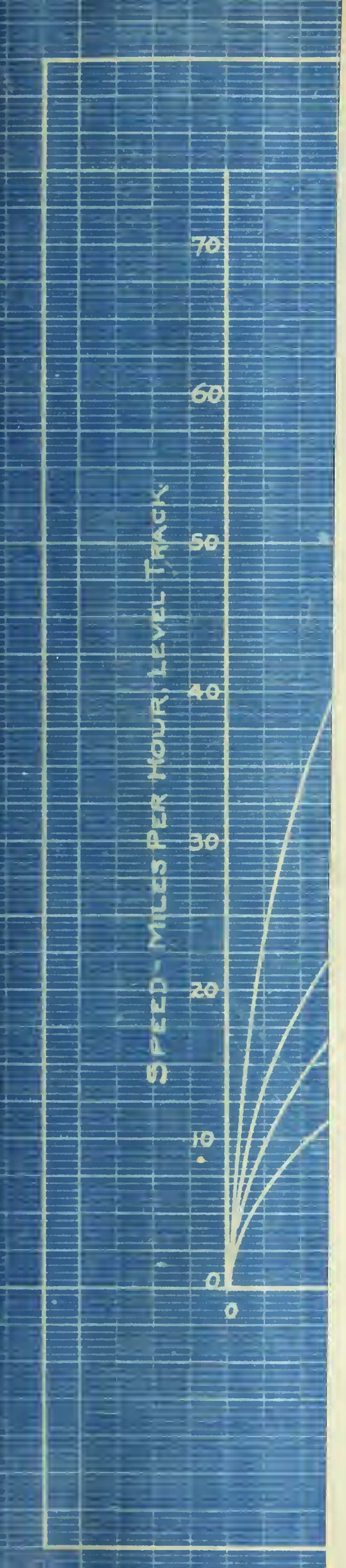

Fig. 31.

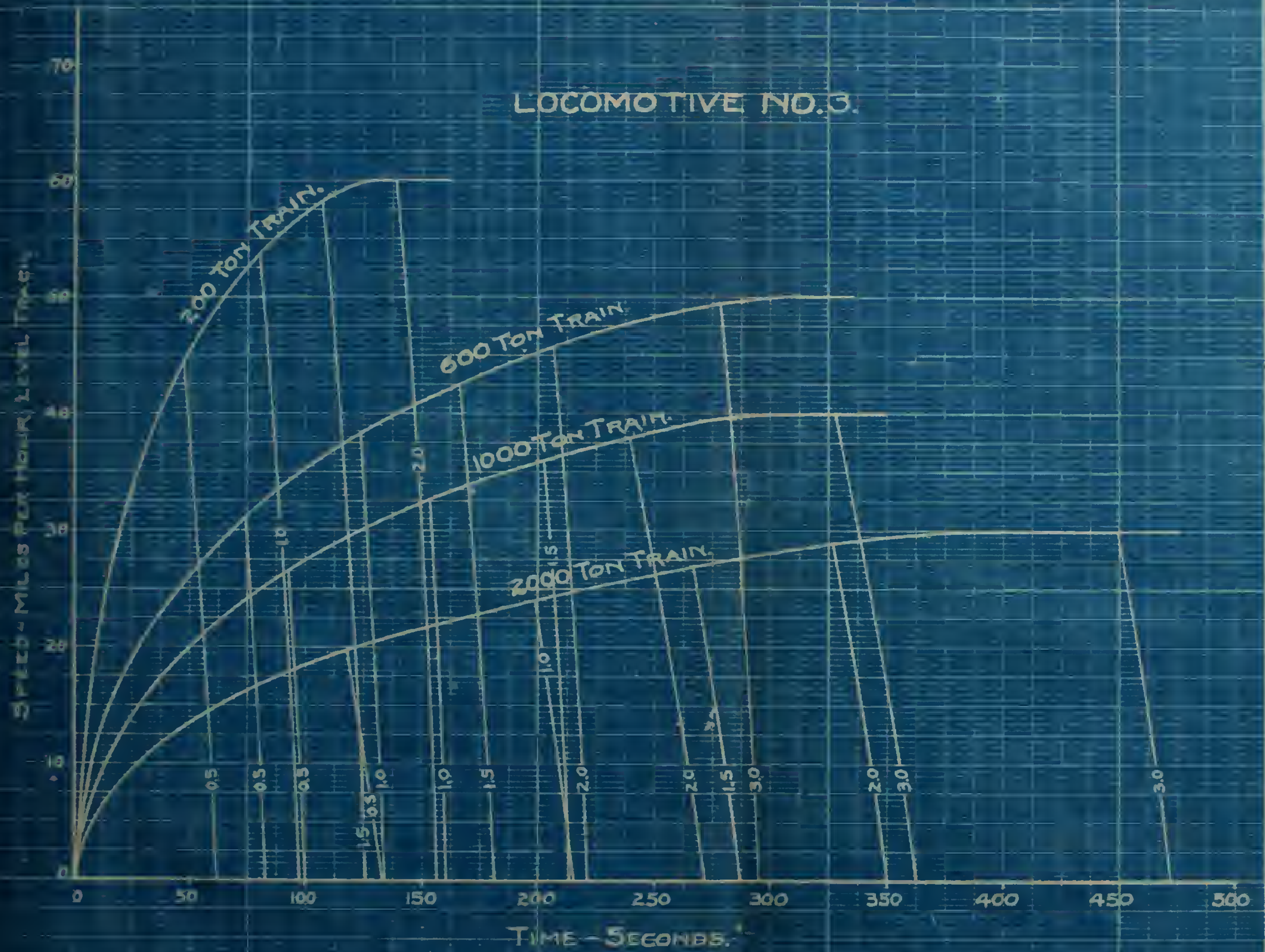

FIG. 31 SPEED-TIME CURVES.

FIG. 32.

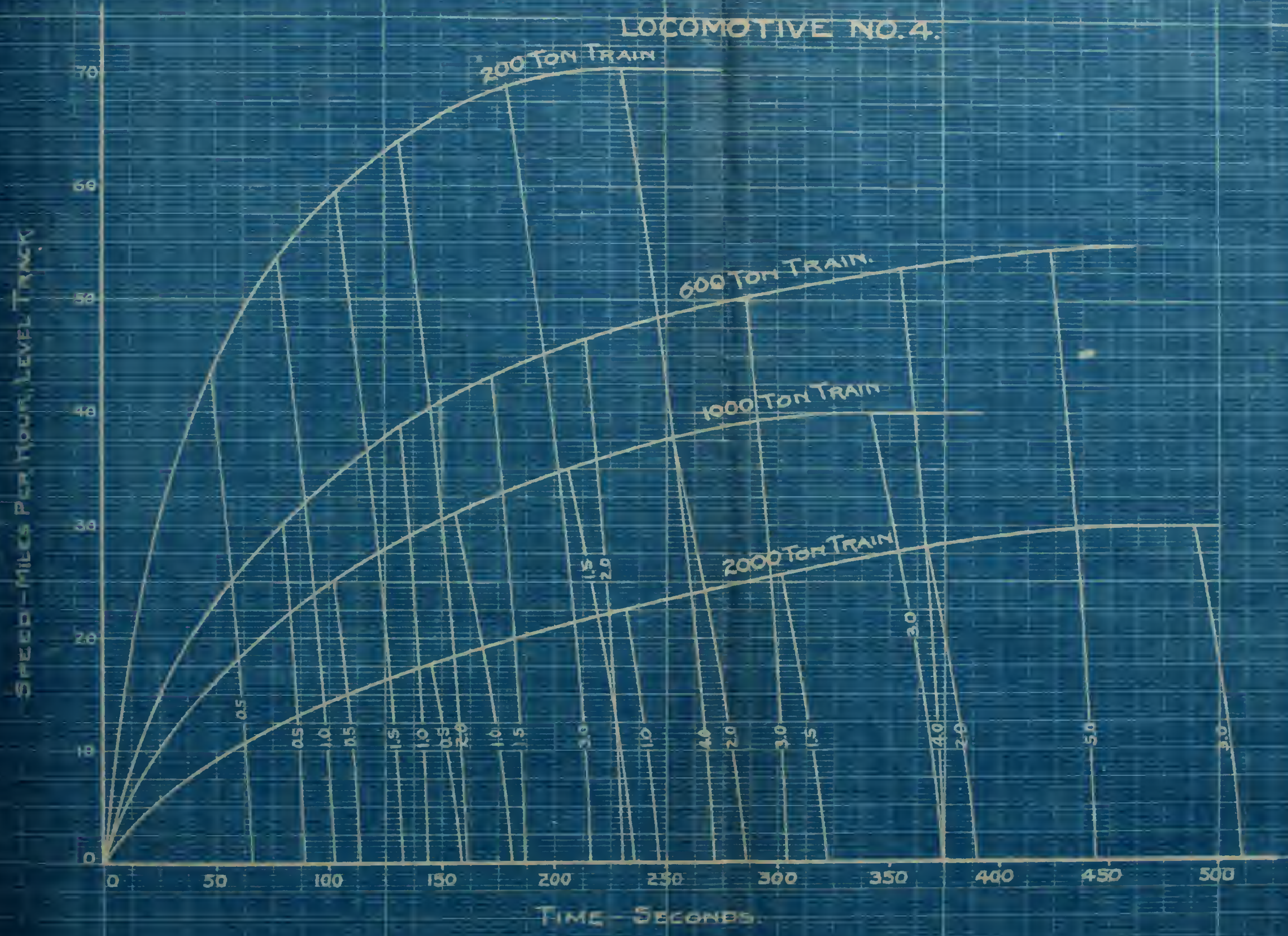

Fig. 32. Speed-Time Curve.

In the problem outlined in this treatise, it is proposed to move a given weight of train over a certain distance in the least possible time. The distances to be traversed, as well as the train weights, have been previously stated in the beginning of this article. It remains to find the time in which each operation can be performed. This has been done by plotting the speed-time curves during acceleration and retardation in such a manner that the area enclosed within their boundaries is proportional to the distance traveled. For instance, take any one of the four sets of speed-time curves represented by Figures 29, 30, 31, or 32, and it is seen that the distance traveled in miles or decimals thereof, is marked on the retardation curve, which finally encloses the area which is proportional to that distance. Attention should be given the fact that no "run curves" are plotted after the train in question has reached its allowable maximum or constant speed, as then it is simply a matter of taking the time and distance for acceleration from one of the Tables XIV, XV, XVI, or XVII, and adding to these values the results of time and distance for constant speed as calculated by the equation,

$$\text{Velocity} = \frac{\text{distance traversed}}{\text{time}}.$$

The time which it takes each locomotive with each train to reach the highest speed permitted by the conditions of the problem and then come to a stop in certain definite distances, is shown on the following pages by Tables XII and XIII. These tables give the least time in which each of the

four locomotives whose characteristics are given in Table I, can make a run between the stations shown on the profiles for the local and through schedules (Figures 6 and 7), when it is operated at the head of each of the four trains which have been selected.

TABLE XII.

TIME IN SECONDS FOR LOCAL SCHEDULE.

Stations	Distance between stations. Miles.	Locomotive Numbers							
		1	2	3	4	1	2	3	4
		200 Ton Train				600 Ton Train			
A	0	0	0	0	0	0	0	0	0
B	0.5	77	68	61	65	114	92	82	90
C	1.0	119	112	97	102	183	150	134	145
D	1.5	157	144	127	133	238	201	181	188
E	2.0	194	178	156	160	289	248	221	230
F	3.0	259	240	216	215	385	335	294	304
G	4.0	322	304	276	270	475	414	366	374
H	5.0	383	364	336	321	565	494	438	444
I	7.0	503	484	456	423	745	654	582	574
J	10.0	683	664	636	676	1015	894	798	770
K	16.0	1043	1024	996	982	1555	1374	1230	1160
		1000 Ton Train				2000 Ton Train			
A	0	0	0	0	0	0	0	0	0
B	0.5	149	118	100	114	223	150	134	159
C	1.0	230	190	160	181	353	246	215	246
D	1.5	300	250	214	235	410	323	286	322
E	2.0	363	308	271	285	558	398	350	390
F	3.0	484	412	362	374	745	544	472	511
G	4.0	604	515	452	464	925	688	592	631
H	5.0	724	618	542	554	1105	832	712	751
I	7.0	964	824	722	734	1465	1120	952	991
J	10.0	1324	1132	992	1004	2005	1552	1312	1351
K	16.0	2044	1748	1532	1544	3085	2416	2032	2071

TABLE XIII.

TIME IN MINUTES FOR THROUGH SCHEDULE.

Train Weights	Locomotive Numbers			
	1	2	3	4
		1% UP GRADE		
200 ton	100.64	86.0	75.45	75.53
600 "	*	200.27	150.37	151.06
1000 "	*	*	200.58	*
2000 "	*	*	*	*
		LEVEL TRACK		
200 ton	51.45	51.0	50.65	43.93
600 "	76.75	68.10	61.40	48.77
1000 "	100.06	87.31	76.58	76.81
2000 "	153.50	122.10	101.91	102.55
		1% DOWN GRADE		
200 ton	38.81	50.60	50.31	38.40
600 "	40.60	51.15	50.90	39.15
1000 "	76.0	76.53	75.50	75.91
2000 "	76.30	76.71	76.10	77.77

* Beyond capacity of locomotive.

TABLE XIV.

TABLE XIV

LOCOMOTIVE NO. 1.

200 TON TRAIN

Speed M.P.H.	Available Tender D-B-P – Lbs.			Available D B P per Ton of Train – Lbs			Resistance per Ton of Train – Lbs			D. B. P. Available for Acceleration Lbs per Ton			Acceleration in M. P. H. P. S.			Avg Acceleration M. P. H. P. S.			Time Required to Produce Changes of Speed as Shown in Col. 1 – Sec.						Distance Traveled to Produce Change of Speed as Shown in Col. 1, – Feet					
	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn Grade	1% Up Grade		Level		1% Dwn. Grade		1% Up Grade		Level		1% Dwn. Grade	
																				Total		Total		Total		Total		Total		Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	13300	15100	16900	66.5	75.5	84.5	23.72	3.72	-16.28	42.8	71.8	100.8	.46	.77	1.07	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	13850	15050	16850	66.3	75.3	84.3	24.00	4.00	-16.00	42.3	71.3	100.3	.45	.76	1.07	.45	.76	1.07	11.1	11.1	6.6	6.6	4.7	4.7	122	122	73	73	52	52
15	11760	13560	15360	58.8	67.8	76.8	24.34	4.34	-15.66	34.5	63.5	92.5	.37	.68	.99	.41	.72	1.03	12.2	23.3	6.9	13.5	4.9	9.6	224	346	127	200	90	142
20	9360	11160	12960	46.8	55.8	64.8	24.74	4.74	-15.26	22.1	51.1	80.1	.24	.54	.85	.31	.61	.92	16.1	39.4	8.2	21.7	5.4	15.0	413	759	210	410	139	281
25	7200	9000	10800	36.0	45.0	54.0	25.20	5.20	-14.80	10.8	39.8	68.8	.12	.43	.73	.18	.49	.79	27.8	67.2	10.2	31.9	6.3	21.3	918	1677	337	747	208	489
30	5630	7430	9230	28.2	37.2	46.2	25.72	5.72	-14.26	2.5	31.5	60.5	.03	.34	.64	.08	.39	.69	62.5	129.7	12.8	44.7	7.2	28.5	2520	4197	516	1263	290	779
35	4475	6275	8075	22.4	31.4	40.4	26.28	6.28	-13.72		25.1	54.1		.27	.58		.31	.61			16.1	60.8	8.2	36.7			768	2031	391	1170
40	3370	5170	6970	16.9	25.9	34.8	26.90	6.94	-13.06		19.0	47.9		.20	.51		.24	.55			20.8	81.6	9.1	45.8			1143	3174	500	1670
45	2560	4360	6160	12.8	21.8	30.8	27.60	7.60	-12.40		14.2	43.2		.15	.46		.18	.49			27.8	109.4	10.2	56.0			1733	4907	636	2306
50	1675	3475	5275	8.4	17.4	26.4	28.40	8.40	-11.60		9.0	38.0		.10	.40		.13	.43			38.5	147.9	11.6	67.6			2680	7587	808	3114
55	975	2775	4575	4.9	13.9	22.9	29.30	9.28	-10.72		4.6	33.6		.05	.36		.08	.38			62.5	210.4	13.2	80.8			4810	12397	1016	4130
60	270	2070	3870	1.4	10.4	19.4	30.10	10.10	-9.90		0.3	29.3		.003	.31		.027	.34			185.2	395.6	14.7	95.5			15600	27997	1240	5370
65		1420	3220		7.1	16.1	31.00	11.00	-9.00			25.1			.27			.29					17.2	112.7					1575	6945
70		800	2600		4.0	13.0	32.00	12.00	-8.00			21.0			.22			.25					20.0	132.7					1980	8925
75		300	2100		1.5	10.5	33.10	13.10	-6.90			17.4			.19			.21					23.8	156.5					2530	11455
80		100	1900		0.5	9.5	34.20	14.20	-5.80			15.3			.16			.18					27.8	184.3					3160	14615
600 TON TRAIN																														
0	—	—	—	—	—	—	—	—	—	—	—	—		—	—		—	—			—	—	—	—			—	—	—	—
5	13300	15100	16900	22.2	25.2	28.2	23.7	3.7	-16.3	—	21.5	44.5		.22	.46		—	—			—	—	—	—			—	—	—	—
10	13250	15050	16850	22.1	25.1	28.1	24.0	4.0	-16.0		21.1	44.1		.22	.46		.22	.46			22.7	22.7	10.9	10.9			250	250	120	120
15	11760	13560	15360	19.6	22.6	25.6	24.3	4.3	-15.7		18.3	41.3		.19	.43		.21	.45			23.8	46.5	11.1	22.0			436	686	204	324
20	9360	11160	12960	15.6	18.6	21.6	24.7	4.7	-15.3		13.9	36.9		.14	.38		.17	.41			29.4	75.9	12.2	34.2			755	1441	313	637
25	7200	9000	10800	12.0	15.0	18.0	25.2	5.2	-14.8		9.8	32.8		.10	.34		.12	.36			41.6	117.5	13.9	48.1			1372	2813	459	1096
30	5630	7430	9230	9.4	12.4	15.4	25.7	5.7	-14.3		6.7	29.7		.07	.31		.09	.33			55.6	173.1	15.2	63.3			2240	5053	613	1709
35	4475	6275	8075	7.5	10.5	13.5	26.3	6.3	-13.7		4.2	27.2		.04	.28		.06	.30			83.3	256.4	16.7	80.0			3970	9023	797	2506
40	[illegible]	5170	6970	5.6	8.6	11.6	26.9	6.9	-13.1		1.7	24.7		.02	.26		.03	.27			166.7	423.1	18.5	98.5			9160	18183	1018	3524
45	2560	4360	6160	4.3	7.3	10.3	27.6	7.6	-12.4			22.7			.24			.25					20.0	118.5					1247	4771
50	1675	3475	5275	2.8	5.8	8.8	28.4	8.4	-11.6			20.4			.21			.23					21.7	140.2					1510	6281
55	375	2775	4575	1.6	4.6	7.6	29.3	9.3	-10.7			18.3			.19			.20					25.0	165.2					1924	8205
60	270	2070	3870	0.5	3.5	6.5	30.1	10.1	-9.9			16.4			.17			.18					27.8	193.0					2340	10545
65		1420	3220		2.4	5.4	31.0	11.0	-9.0			14.4			.15			.16					31.3	224.3					2870	13415
70		800	2600		1.3	4.3	32.0	12.0	-8.0			12.3			.13			.14					35.7	260.0					3530	16945
7		300	2100		0.5	3.5	33.1	13.1	-6.9			10.4			.11			.12					41.7	301.7					4430	21375
80		100	1900		0.2	3.2	34.2	14.2	-5.8			9.0			.09			.10					50.0	351.7					5690	27065
1000 TON TRAIN																														
0	—	—	—	—	—	—	—	—	—		—	—					—	—			—	—	—	—			—	—	—	—
5	13300	15100	16900	13.3	15.1	16.9	24.0	4.00	-16.0		11.1	32.9					—	—			—	—	—	—			—	—	—	—
10	13250	15050	16850	13.3	15.1	16.9	24.3	4.30	-15.7		10.8	32.6					.12	.35			41.7	41.7	14.3	14.3			459	459	157	157
15	11760	13560	15360	11.8	13.6	15.4	24.6	4.6	-15.4		9.0	30.8					.11	.34			45.5	87.2	14.7	29.0			835	1294	270	427
20	9360	11160	12960	9.4	11.2	13.0	25.0	5.0	-15.0		6.2	28.0					.09	.32			55.6	142.8	15.6	44.6			1425	2719	401	828
25	7200	9000	10800	7.2	9.0	10.8	25.5	5.5	-14.5		3.5	25.3					.06	.29			83.3	226.1	17.2	61.8			2750	5469	568	1396
30	5630	7430	9230	5.6	7.4	9.2	26.0	6.0	-14.0		1.4	23.2					.03	.26			166.7	392.8	19.2	81.0			6720	12189	775	2171
35	4475	6275	8075	4.5	6.3	8.1	26.0	6.6	-13.4			21.5						.24					20.8	101.8					992	3163
40	3370	5170	6970	3.4	5.2	7.0	27.3	7.3	-12.7			19.7						.22					22.7	124.5					1248	4411
2000 TON TRAIN																														
0	—	—	—	—	—	—	—	—	—	—	—	—					—	—			—	—	—	—			—	—	—	—
5	13300	15100	16900	6.7	7.6	8.5	24.0	4.0	16.0		3.6	24.5					—	—			—	—	—	—			—	—	—	—
10	13250	15050	16850	6.6	7.5	8.4	24.3	4.3	-15.7		3.2	24.1					035	.26			142.8	142.8	19.2	19.2			1570	1570	211	211
15	11760	13560	15360	5.9	6.8	7.7	24.6	4.6	15.4		2.2	23.1					025	.25			200.0	342.8	20.0	39.2			3670	5240	367	578
20	9360	11160	12960	4.7	5.6	6.5	25.0	0	15.0		0.6	21.5					015	.24			333.3	676.1	20.8	60.0			8550	13790	534	1112
25	7200	9000	10800	3.6	4.5	5.4	25.5	5	14.5			19.9						.22					22.7	82.7					750	1862
30	5630	7430	9230	2.8	3.7	4.6	26.0	6.0	14.0			18.6						.21					23.8	106.5					960	2822
35	4475	6275	8075	2.2	3.4	4.0	26.6	6.6	13.4			17.4						.20					25.0	131.5					1190	4012
40	3370	5170	6970	1.7	6	3.5	27.3	7.3	12.7			16.2						.18					27.8	159.3					1528	5540

200 TON TRAIN.

Speed M.P.H.	Retardation in M. P. H. P. S.			Avg Retardation in M.P.H.P.S.			Time Required to Produce Changes of Speed as Shown in Col. 1, – Sec.						Distance Traveled to Produce Changes of Speed as Shown in Col. 1, – Sec.					
	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn Grade	1% Up Grade		Level		1% Dwn Grade		1% Up Grade		Level		1% Dwn Grade	
								Total		Total		Total		Total		Total		Total
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
80			—			—					—	—					—	—
75			2.13			2.20					2.27	2.27					258	258
70			1.91			1.97					2.54	4.81					270	528
65			1.82			1.86					2.69	7.50					266	794
60			1.76			1.79					2.79	10.29					256	1050
55		2.9	1.69		2.9	1.73			1.72	1.72	2.9	13.20			145	145	244	1294
50		2.8	1.64		2.85	1.66			1.75	3.47	3.0	16.20			135	280	231	1524
45		2.6	1.64		2.10	1.64			1.85	5.32	3.1	18.3			130	410	217	1741
40		2.6	1.64		2.60	1.64			1.92	7.24	3.1	21.4			120	530	193	1934
35		2.7	1.66		2.65	1.65			1.88	9.12	3.0	24.4			103	633	167	2099
30		2.7	1.72		2.70	1.69			1.85	10.97	3.0	27.4			88	721	143	2242
25	3.46	2.94	1.82	3.46	2.82	1.77	1.45	1.45	1.77	12.74	2.8	30.2	59	59	71	792	113	2355
20	3.73	3.23	2.21	3.60	3.09	2.02	1.39	2.84	1.62	14.36	2.5	32.7	46	105	53	845	83	2438
15	4.00	3.59	2.36	3.86	3.40	2.29	1.30	4.14	1.47	15.83	2.2	34.9	33	138	38	883	57	2495
10	4.00	4.00	2.55	4.00	3.70	2.46	1.25	5.39	1.32	17.15	2.0	36.9	23	161	24	907	37	2532
5	4.00	4.00	3.04	4.00	4.00	2.80	1.25	6.64	1.25	18.40	1.8	38.7	16	175	14	921	20	2552
0	4.00	4.00	3.00	4.00	4.00	3.02	1.25	7.89	1.25	19.65	1.7	40.4	5	180	5	926	6	2558
600 TON TRAIN																		
80			—			—					—	—					—	—
75			2.00			2.00					2.5	2.5					227	227
70			1.93			1.96					2.6	5.1					277	504
65			1.85			1.89					2.7	7.8					267	771
60			1.78			1.81					2.8	10.6					256	1027
55			1.72			1.75					2.9	13.5					244	1271
50			1.67			1.69					3.0	16.5					231	1502
45			1.66			1.67					3.0	19.5					210	1712
40			1.66			1.66					3.0	22.5					187	1899
35		2.97	1.69		2.97	1.68			1.7	1.7	3.0	25.5			94	94	165	2064
30		3.11	1.75		3.04	1.72			1.6	2.3	2.9	28.4			76	170	138	2202
25		3.29	1.85		3.10	1.80			1.6	3.8	2.8	31.2			65	235	113	2315
20		3.54	2.05		3.41	1.95			1.5	6.4	2.6	33.8			50	285	86	2401
15		3.91	2.25		3.72	2.15			1.3	7.7	2.3	36.1			33	318	59	2460
10		4.00	2.61		3.96	2.43			1.2	9.0	2.1	38.2			24	342	39	2499
5		4.00	3.10		4.00	2.86			1.3	10.3	1.7	39.9			14	356	19	2518
0		4.00	3.00		4.00	3.06			1.3	11.6	1.6	41.5			5	361	6	2524
1000 TON TRAIN																		
40			—			—					—	—					—	—
35			1.17			1.17					4.3	4.3					236	236
30			1.20			1.19					4.2	8.5					200	436
25		1.45	1.29		1.45	1.25			3.4	3.4	4.0	12.5			137	137	161	597
20		1.57	1.39		1.51	1.34			3.3	6.7	3.7	16.2			109	246	122	719
15		1.74	1.57		1.65	1.48			3.0	9.7	3.4	19.6			77	323	87	806
10		1.95	1.74		1.84	1.66			2.7	12.4	3.0	22.6			50	373	55	861
5		1.95	1.74		1.95	1.74			2.6	15.0	2.9	25.5			29	402	32	893
0		1.95	1.74		1.95	1.74			2.6	17.6	2.9	28.4			10	412	10	903
2000 TON TRAIN																		
40			—			—					—	—					—	—
35			1.18			1.18					4.2	4.2					231	231
30			1.21			1.20					4.2	8.4					200	431
25			1.30			1.25					4.0	12.4					161	592
20			1.40			1.35					3.7	16.1					122	714
15		1.74	1.78		1.74	1.49			1.9	1.9	3.4	19.5			49	49	87	801
10		1.95	1.75		1.85	1.66			1.7	3.6	3.0	22.5			31	80	55	856
5		1.95	1.75		1.95	1.75			1.6	5.2	2.9	25.4			18	98	32	888
0		1.95	1.75		1.95	1.75			1.6	6.8	2.9	28.3			6	104	10	898

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TABLE XV

TABLE XV

LOCOMOTIVE NO. 2.

Speed M.P.H.	Available Tender D-B-P in Lbs.			Available DBP per Ton of Train – Lbs			Resistance per Ton of Train – Lbs			D.B.P. Available for Acceleration Lbs. per Ton			Acceleration in M.P.H.P.S.			Avg Acceleration M.P.H.P.S.			Time Required to Produce Changes of Speed as Shown in Col. 1 – Sec.						Distance Traveled to Produce Changes of Speed as Shown in Col. 1 – Feet					
	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn. Grade	1% Up Grade		Level		1% Dwn. Grade		1% Up Grade		Level		1% Dwn. Grade	
																				Total		Total		Total		Total		Total		Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
200 TON TRAIN																														
0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	36190	38450	40710	181.0	192.3	203.6	23.72	3.72	-16.28	157.3	188.6	219.9	1.67	2.01	2.34	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	26390	28650	30910	132.0	143.3	154.6	24.00	4.00	-16.00	108.0	139.3	170.6	1.15	1.48	1.82	1.41	1.75	2.08	3.52	3.52	2.85	2.85	2.40	2.40	39	39	31	31	26	26
15	17990	20250	22510	90.0	101.3	112.6	24.34	4.34	-15.66	65.7	97.0	128.3	.70	1.03	1.37	.93	1.26	1.60	5.38	8.90	3.97	6.82	3.12	5.52	99	138	73	104	57	83
20	13190	15450	17710	66.8	77.3	88.6	24.74	4.74	-15.26	41.3	72.6	103.9	.44	.77	1.11	.57	.90	1.24	8.18	17.68	5.55	12.37	4.06	9.58	225	363	142	246	104	181
25	10090	12350	14610	50.5	61.8	73.1	25.20	5.20	-14.80	25.3	56.6	87.9	.27	.60	.94	.36	.69	1.03	13.88	31.56	7.25	19.62	4.85	14.43	458	821	234	485	160	341
30	7790	10050	12310	39.0	50.3	61.6	25.72	5.72	-14.28	13.3	44.6	75.9	.14	.48	.81	.22	.54	.88	22.70	54.26	9.27	28.89	5.68	20.11	916	1737	379	839	229	576
35	5890	8150	10410	29.5	40.8	52.1	26.28	6.28	-13.72	3.2	34.5	65.8	.03	.37	.70	.09	.43	.76	55.55	109.81	11.62	40.51	6.58	26.63	2645	4382	554	1413	314	890
40	4440	6700	8960	22.2	33.5	44.8	26.94	6.94	-13.06		26.6	57.9		.28	.62		.33	.66			15.14	55.65	7.57	34.26			832	2245	416	1306
45	3090	5350	7610	15.5	26.8	38.1	27.60	7.60	-12.40		19.2	50.5		.20	.54		.24	.58			20.80	76.45	8.62	42.88			1276	3541	537	1843
50	1990	4250	6510	10.0	21.3	32.6	28.40	8.40	-11.60		12.9	44.2		.14	.47		.17	.51			29.40	105.85	9.81	52.69			2050	5591	689	2527
55	990	3250	5510	5.0	16.3	27.6	29.28	9.28	-10.72		7.0	38.3		.07	.41		.11	.44			45.50	151.35	11.35	64.04			3500	9091	879	3401
60	90	2350	4610	0.5	11.8	23.1	30.10	10.10	-9.90		1.7	33.0		.02	.35		.05	.38			100.00	251.35	13.14	77.18			8930	17521	1107	4508
600 TON TRAIN																														
0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	36190	38450	40710	60.3	64.1	67.9	23.72	3.72	-16.28	36.6	60.4	84.2	.38	.63	.88	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	26390	28650	30910	44.0	47.8	51.5	24.00	4.00	-16.00	20.0	43.8	67.5	.21	.46	.70	.30	.55	.79	16.67	16.67	9.10	9.10	6.33	6.33	183	183	100	100	70	70
15	17990	20250	22510	30.0	33.8	37.5	24.34	4.34	-15.66	5.7	29.5	53.2	.06	.31	.55	.14	.39	.63	35.70	52.37	12.00	21.90	7.94	14.27	654	837	235	335	145	215
20	13190	15450	17710	21.8	25.8	29.5	24.74	4.74	-15.26		21.1	44.8		.22	.47		.29	.51			17.21	39.11	9.80	24.07			442	777	251	466
25	10090	12350	14610	16.8	20.6	24.4	25.20	5.20	-14.80		15.4	39.2		.16	.41		.19	.44			26.30	65.41	11.36	35.43			868	1645	375	841
30	7790	10050	12310	[illegible]	[illegible]	[illegible]	25.72	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]			35.70	101.11	12.81	48.24			1440	3085	617	[illegible]
35	5890	8150	10410	9.8	13.6	17.4	26.28	6.28	-13.72		7.3	31.1		.08	.32		.10	.34			50.00	151.11	14.10	62.14			2382	5467	706	2064
40	4440	6700	8960	7.6	11.2	14.9	26.94	6.94	-13.06		4.3	28.0		.05	.29		.07	.31			71.45	222.56	16.11	79.25			3930	9397	886	2950
45	3090	5390	7610	5.2	8.9	12.7	27.60	7.60	-12.40		1.3	25.1		.01	.26		.03	.28			166.67	389.23	17.84	97.09			10380	19777	1110	4060
50	1990	4250	6510	3.3	7.1	10.9	28.40	8.40	-11.60			22.5			.23			.25					20.00	117.09					1393	5403
55	990	3250	5510	1.7	5.4	9.2	29.28	9.28	-10.72			19.9			.21			.22					22.70	139.79					1748	7201
60	90	2350	4610	0.2	3.3	7.7	30.10	10.10	-9.90			17.6			.18			.20					25.00	164.79					2110	9311
1000 TON TRAIN																														
0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	36190	38450	40710	36.2	38.5	40.7	24.01	4.01	-15.99	12.2	34.5	56.7	.13	.37	.60	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	26390	28650	30910	26.4	28.7	30.9	24.27	4.27	-15.73	2.1	24.4	46.6	.02	.26	.50	.08	.32	.55	62.50	62.50	15.62	15.62	9.09	9.09	688	688	172	172	100	100
15	17990	20250	22510	18.0	20.3	22.5	24.60	4.60	-15.40		15.7	37.9		.17	.40		.22	.45			22.70	38.32	11.10	20.19			416	588	203	303
20	13190	15450	17710	13.2	15.5	17.7	25.00	5.00	-15.00		10.5	32.7		.11	.35		.14	.39			35.70	74.02	12.81	33.00			917	1505	329	632
25	10090	12350	14610	10.1	12.4	14.6	25.47	5.47	-14.53		6.9	29.1		.07	.31		.09	.33			55.55	129.57	15.14	48.14			1830	3335	500	1132
30	7790	10050	12310	7.8	10.1	12.3	26.00	6.00	-14.00		4.1	26.3		.04	.28		.06	.30			83.33	212.90	16.67	65.81			3360	6695	672	1804
35	5890	8150	10410	5.9	8.2	10.4	26.62	6.62	-13.38		1.6	23.8		.02	.25		.03	.27			166.67	379.07	18.50	84.31			7940	14635	882	2686
40	4440	6700	8960	4.4	6.7	9.0	27.30	7.30	-12.70			21.7			.23			.24					20.82	105.13					1144	3830
2000 TON TRAIN																														
0	—	—	—	—	—	—	—	—	—		—	—		—	—		—	—			—	—	—	—			—	—	—	—
5	36190	38450	40710	18.1	19.2	20.4	24.01	4.01	-15.99		15.2	36.4		.16	.39		—	—			—	—	—	—			—	—	—	—
10	26390	28650	30910	13.2	14.3	15.5	24.27	4.27	-15.73		10.0	31.2		.11	.33		.14	.36			35.70	35.70	13.87	13.87			393	393	153	153
15	17990	20250	22510	9.0	10.1	11.3	24.60	4.60	-15.40		5.5	26.7		.06	.28		.09	.32			55.55	91.25	15.61	29.48			1017	1410	286	439
20	13190	15450	17710	6.6	7.7	8.9	25.00	5.00	-15.00		2.7	23.9		.03	.20		.05	.27			100.00	191.25	18.50	47.98			2567	3977	475	914
25	10090	12350	14610	5.0	6.2	7.3	25.47	5.47	-14.53		0.7	21.8			.23		.02	.24			250.00	441.25	20.82	68.80			8250	12227	688	1602
30	7790	10050	12310	3.9	5.0	6.2	26.00	6.00	-14.00			20.2			.22			.23					21.74	90.54					877	2479
35	5890	8150	10410	2.9	4.1	5.2	26.62	6.62	-13.38			19.6			.21			.22					22.70	113.24					1082	3561
40	4440	6700	8960	2.2	3.4	4.5	27.30	7.30	-12.70			19.2			.18			.19					26.30	139.54					1445	5006

Speed M.P.H.	Retardation in M.P.H.P.S.			Avg. Retardation in M.P.H.P.S.			Time Required to Produce Changes of Speed as Shown in Col. 1 – Sec.						Distance Traveled to Produce Changes of Speed as Shown in Col. 1 – Sec.					
	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn. Grade	1% Up Grade		Level		1% Dwn Grade		1% Up Grade		Level		1% Dwn Grade	
								Total		Total		Total		Total		Total		Total
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
200 TON TRAIN																		
60		—	—		—	—			—	—	—	—			—	—	—	—
55		2.71	2.50		2.71	2.50			1.8	1.8	2.0	2.0			152	152	169	169
50		2.60	2.33		2.65	2.45			1.9	3.7	2.0	4.0			146	298	159	328
45		2.57	2.34		2.58	2.37			1.9	5.6	2.1	6.1			132	430	146	463
40		2.56	2.34		2.56	2.34			2.0	7.6	2.1	8.2			125	555	131	600
35		2.58	2.36		2.57	2.35			1.9	9.5	2.1	10.3			105	660	115	715
30	3.25	2.68	2.47	3.25	2.63	2.41	1.5	1.5	1.9	11.4	2.1	12.4	72	72	91	751	100	815
25	3.40	2.88	2.68	3.32	2.78	2.57	1.5	3.0	1.8	13.2	2.0	14.4	60	132	77	828	81	896
20	3.66	3.20	2.98	3.53	3.04	2.83	1.4	4.4	1.6	14.8	1.8	16.2	96	178	60	888	60	956
15	4.00	3.53	3.32	3.84	3.37	3.15	1.3	5.7	1.5	16.3	1.6	17.8	33	211	41	929	41	997
10	4.00	4.00	3.84	4.00	3.80	3.58	1.3	7.0	1.3	17.6	1.4	19.2	24	235	27	956	26	1023
5	4.00	4.00	4.00	4.00	4.00	3.92	1.2	8.2	1.3	18.9	1.3	20.5	13	248	14	970	14	1037
0	4.00	4.00	4.00	4.00	4.00	4.00	1.2	9.4	1.2	20.1	1.2	21.7	4	252	4	974	5	1042
600 TON TRAIN																		
60			—			—					—	—					—	—
55			2.59			2.59					1.9	1.9					160	160
50			2.46			2.53					2.0	3.9					154	314
45			2.43			2.45					2.0	5.9					139	453
40		2.65	2.41		2.63	2.42			1.9	1.9	2.1	6.0			118	118	131	584
35		2.65	2.44		2.64	2.43			1.9	3.8	2.1	10.1			105	223	115	699
30		[illegible]	[illegible]		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]
25		2.96	2.78		2.87	2.66			1.7	7.3	1.9	14.0			69	378	77	871
20		3.28	3.08		3.12	2.93			1.6	8.9	1.7	15.7			53	431	56	927
15		3.64	3.43		3.46	3.25			1.4	10.3	1.5	17.2			36	467	39	966
10	4.00	4.00	4.00	4.00	3.88	3.71	1.3	1.3	1.3	11.6	1.3	18.5	24	24	24	491	24	990
5	4.00	4.00	4.00	4.00	4.00	4.00	1.2	2.5	1.3	12.9	1.2	19.8	13	37	14	505	14	1004
0	4.00	4.00	4.00	4.00	4.00	4.00	1.2	3.7	1.2	14.1	1.2	21.0	4	41	4	509	5	1009
1000 TON TRAIN																		
40			—			—					—	—					—	—
35			.65			.65					7.7	36.9					423	423
30		1.01	.68		1.01	.67			5.0	5.0	7.5	44.4			238	238	357	780
25		1.05	.75		1.03	.72			4.9	9.9	7.0	51.4			198	436	282	1062
20		1.14	.84		1.09	.79			4.6	14.5	6.3	57.7			152	588	216	1278
15		1.25	.95		1.20	.90			4.2	18.7	5.5	63.2			108	696	141	1419
10		1.38	1.10		1.32	1.02			3.8	22.5	4.9	68.1			70	766	90	1509
5	1.65	1.50	1.16	1.65	1.44	1.13	3.0	3.0	3.5	26.0	4.4	72.5	33	33	37	799	48	1557
0	1.65	1.50	1.16	1.65	1.50	1.16	3.0	6.0	3.3	29.3	4.3	76.8	11	44	12	811	15	1572
2000 TON TRAIN																		
40			.66			—					—	—					—	—
35			.67			.67					7.5	36.1					412	412
30			.70			.69					7.3	43.4					348	760
25			.76			.73					6.8	50.2					274	1034
20		1.10	.85		1.10	.80			4.5	4.5	6.3	56.5			148	148	216	1250
15		1.27	.96		1.18	.90			4.2	8.7	5.6	62.1			108	256	144	1394
10		1.40	1.13		1.34	1.04			3.7	12.4	4.8	66.9			68	324	88	1482
5		1.50	1.27		1.45	1.20			3.4	15.8	4.2	71.1			37	361	46	1528
0		1.50	1.27		1.50	1.27			3.3	19.1	3.9	75.0			12	373	14	1542

157c

TABLE XVI

TABLE XVI

LOCOMOTIVE NO. 3

Speed M.P.H	Available Tender D.B.P. in Lbs			Available D.B.P per Ton of Train – Lbs			Resistance per Ton of Train – Lbs			D.B.P. Available for Acceleration Lbs per Ton			Acceleration in M.P.H.P.S			Avg Acceleration M.P.H.P.S.			Time Required to Produce Changes of Speed as Shown in Col. 1 – Sec.						Distance Traveled to Produce Changes of Speed as Shown in Col. 1 – Feet					
	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn. Grade	1% Up Grade	Level	1% Dwn. Grade	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn. Grade	1% Up Grade		Level		1% Dwn. Grade		1% Up Grade		Level		1% Dwn. Grade	
																				Total		Total		Total		Total		Total		Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
200 TON TRAIN																														
0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	38430	92110	45790	192.2	210.6	229.0	23.72	3.72	−16.28	168.5	206.9	245.3	1.80	2.20	2.61	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	36805	90485	49165	184.0	202.4	220.8	24.00	4.00	−16.00	160.0	198.4	236.0	1.70	2.11	2.52	1.75	2.16	2.57	2.9	2.9	2.3	2.3	1.9	1.9	32	32	25	25	21	21
15	25680	29360	33040	128.4	146.8	165.2	29.39	4.34	−19.66	103.1	142.5	181.9	1.10	1.52	1.94	1.40	1.82	2.23	3.6	6.5	2.8	5.1	2.2	4.1	66	98	51	76	40	61
20	18390	22070	25750	92.0	110.4	128.8	24.74	4.74	−15.26	67.3	105.7	144.1	0.72	1.13	1.54	.91	1.33	1.74	5.5	12.0	3.8	8.9	2.9	7.0	141	239	98	174	74	135
25	13980	17660	21340	69.6	88.3	106.7	25.20	5.20	−14.80	44.7	83.1	121.5	0.48	0.89	1.29	.60	1.01	1.44	8.3	20.3	5.0	13.9	3.5	10.5	274	513	165	339	115	250
30	11000	14680	18360	55.0	73.4	91.8	25.72	5.72	−14.28	29.3	67.7	106.1	0.31	0.72	1.13	.40	.81	1.21	10.5	32.8	6.2	19.1	4.1	14.6	505	1018	250	589	165	415
35	8320	12000	15680	41.6	60.0	78.9	26.28	6.28	−13.72	15.3	53.7	92.1	0.16	0.57	0.98	.29	.65	1.06	20.8	53.6	7.7	26.8	4.7	19.3	992	2010	367	956	224	639
40	6410	10090	13770	37.1	50.5	68.9	26.94	6.94	−13.06	6.2	43.6	82.0	0.06	0.46	0.87	.11	.52	.93	45.4	99.0	7.6	36.4	5.9	24.7	2990	4502	528	1484	297	936
45	4550	8230	11910	22.8	41.2	59.6	27.60	7.60	−12.40		33.6	72.0		0.36	0.77		.01	.82			12.2	48.6	6.4	30.8			760	2244	380	1316
50	3060	6740	10420	15.3	33.7	52.1	28.40	8.40	−11.60		25.3	63.7		0.27	0.68		.32	.73			15.6	64.2	6.8	37.6			1086	3330	474	1790
55	1800	5480	9160	9.0	27.4	45.8	29.28	9.23	−10.72		18.1	56.8		0.19	0.60		.23	.64			21.7	85.9	7.8	45.9			1670	5000	600	2390
60	620	4300	7980	31	21.5	39.9	30.10	10.10	−9.90		11.4	49.8		0.12	0.53		.16	.51			31.2	117.1	8.8	54.2			2630	7630	742	3132
600 TON TRAIN																														
0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	38430	42110	45790	64.1	70.2	76.3	23.72	3.72	−16.28	40.4	66.5	92.6	0.42	0.69	0.96	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	36805	40485	44165	61.3	67.5	73.6	24.00	4.00	−16.00	37.3	63.5	89.6	0.39	0.66	0.93	.41	.68	.95	12.2	12.2	7.4	7.9	5.3	5.3	134	134	82	82	58	58
15	25680	29360	33040	42.8	48.9	55.1	24.34	4.34	−15.66	18.5	44.6	70.8	0.19	0.46	0.74	.29	.56	.84	17.2	29.4	8.9	16.3	6.0	11.3	316	450	163	245	110	168
20	18390	22070	25750	30.7	36.8	46.3	24.74	4.74	−15.26	6.0	32.1	61.6	0.06	0.33	0.64	.13	.40	.69	38.4	67.8	12.5	28.8	7.2	18.6	986	1435	321	566	185	353
25	13980	17660	21340	23.3	29.4	35.6	25.20	5.20	−14.80		24.2	50.4		0.25	0.52		.29	.58			17.2	46.0	8.6	27.1			560	1134	284	637
30	11000	14680	18360	18.3	24.6	30.6	25.72	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	37.1			[illegible]	[illegible]	[illegible]	[illegible]
35	8320	12000	15680	13.9	20.0	26.1	26.28	6.28	−13.72		13.7	39.8		0.14	0.41		.17	.44			29.4	97.1	11.4	48.5			1400	3410	543	1683
40	6410	10090	13770	10.7	16.8	23.0	26.94	6.94	−13.06		9.9	36.1		0.10	0.38		.12	.40			41.7	138.8	12.5	61.0			2290	5700	688	2271
45	4550	8230	11910	7.6	13.7	19.9	27.60	7.60	−12.40		6.1	32.3		0.06	0.34		.08	.36			62.5	201.3	13.9	74.9			3880	9580	872	3143
50	3060	6740	10420	5.0	11.2	17.4	28.40	8.40	−11.60		2.8	29.0		0.03	0.30		.05	.32			100.0	301.3	15.6	90.5			6970	16550	1086	4229
55	1800	5480	9160	3.0	9.1	15.3	29.28	9.28	−10.72			26.0			0.27			.29					17.2	107.7					1324	5553
60	620	4300	7980	1.0	7.2	13.3	30.10	10.10	−9.90			23.2			0.24			.26					19.2	126.9					1618	7171
1000 TON TRAIN																														
0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	38430	42110	45790	38.4	42.1	45.8	24.01	4.01	−15.99	14.4	38.1	61.8	0.15	0.41	0.66	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	36805	40485	44165	36.8	40.5	44.2	24.27	4.27	−15.73	12.5	36.2	59.9	0.13	0.39	0.64	0.14	.40	.65	35.7	35.7	12.5	12.5	7.7	7.7	393	393	138	138	85	85
15	25680	29360	33040	25.7	29.4	33.0	24.60	4.60	−15.40	1.1	24.8	48.4	0.01	0.26	0.52	.07	.33	.58	71.4	107.1	15.1	27.6	8.6	16.3	1310	1703	277	415	158	243
20	18390	22070	25750	18.4	22.1	25.8	25.00	5.00	−15.00		17.1	40.8		0.18	0.43		.22	.48			22.7	50.3	10.4	26.7			582	997	267	510
25	13980	17660	21340	14.0	17.7	21.3	25.47	5.47	−14.53		12.2	35.8		0.13	0.38		.16	.42			31.2	81.5	11.9	38.6			1028	2025	394	909
30	11000	14680	18360	11.0	14.7	18.4	26.00	6.00	−14.00		8.7	32.4		0.09	0.35		.11	.37			45.4	126.9	13.5	52.1			1830	3855	546	1450
35	8320	12000	15680	8.3	12.0	15.7	26.62	6.62	−13.38		5.4	29.1		0.06	0.31			.33			62.5	189.4	15.1	67.2			2980	6835	720	2170
40	6410	10090	13770	6.4	10.1	13.8	27.30	7.30	−12.70		2.8	26.6		0.03	0.28			.20			100.0	289.4	16.7	83.9			5500	12335	920	3090
2000 TON TRAIN																														
0	—	—	—	—	—	—	—	—	—	—	—	—		—	—		—	—			—	—	—	—			—	—	—	—
5	38430	42110	45790	19.2	21.1	22.9	24.01	4.01	−15.99		17.1	38.9		0.18	0.41		—	—			—	—	—	—			—	—	—	—
10	36805	40485	44165	18.4	20.2	22.1	24.27	4.27	−15.73		15.9	37.8		0.17	0.40		.18	.41			27.8	27.8	12.2	12.2			306	306	134	134
15	25680	29360	33040	12.8	14.7	16.5	24.60	4.60	−15.40		10.1	31.9		0.11	0.34		.14	.37			35.7	63.5	13.5	25.7			655	961	248	382
20	18390	22070	25750	9.2	11.0	12.9	25.00	5.00	−15.00		6.0	27.9		0.06	0.30		.09	.32			55.6	119.1	15.6	41.3			1425	2386	400	782
25	13980	17660	21340	7.0	8.8	10.7	25.47	5.47	−14.43		3.3	25.2		0.04	0.27		.05	.29			100.0	219.1	17.2	58.5			3300	5686	568	1350
30	11000	14680	18360	5.5	7.3	9.2	26.00	6.00	−14.00		1.3	23.2		0.01	0.25		.03	.26			166.7	385.8	19.2	77.7			6730	12916	775	2125
35	8320	12000	15680	4.2	6.0	7.8	26.62	6.62	−13.38			21.2			0.23			.24					20.8	98.5					992	3117
40	6410	10090	13770	3.2	5.0	6.9	27.30	7.30	−12.70			19.6			0.21			.22					22.7	121.2					1248	4365

Speed M.P.H.	Retardation in M.P.H.P.S.			Avg Retardation in M.P.H.P.S.			Time Required to Produce Changes of Speed as Shown in Col. 1 – Sec.						Distance Traveled to Produce Changes of Speed as Shown in Col. 1 – Sec.					
	1% Up Grade	Level	1% Dwn Grade	1% Up Grade	Level	1% Dwn Grade	1% Up Grade		Level		1% Dwn Grade		1% Up Grade		Level		1% Dwn Grade	
								Total		Total		Total		Total		Total		Total
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
200 TON TRAIN																		
60		—	—		—	—			—	—	—	—			—	—	—	—
55		2.63	2.42		2.63	2.42			1.9	1.9	2.1	2.1			160	160	177	177
50		2.52	2.30		2.58	2.36			1.9	3.8	2.1	4.2			146	306	162	339
45		2.48	2.27		2.58	2.28			2.0	5.8	2.2	6.4			140	446	152	491
40		2.47	2.26		2.47	2.26			2.0	7.8	2.2	8.6			125	571	137	628
35	3.04	2.50	2.28	3.04	2.49	2.27	1.6	1.6	2.0	9.8	2.2	10.8	87	87	110	681	121	749
30	3.15	2.60	2.39	3.10	2.55	2.33	1.6	3.2	2.0	11.8	2.1	12.9	76	163	95	776	100	849
25	3.30	2.82	2.68	3.23	2.71	2.50	1.5	4.7	1.8	13.6	2.0	14.9	61	224	73	849	81	930
20	3.56	3.09	2.88	3.43	2.95	2.74	1.5	6.2	1.7	15.3	1.8	16.7	50	274	56	905	60	990
15	3.90	3.42	3.20	3.73	3.25	3.04	1.3	7.5	1.5	16.8	1.6	18.3	33	307	39	944	41	1031
10	4.00	3.93	3.68	3.95	3.67	3.44	1.3	8.8	1.4	18.2	1.5	19.8	24	331	26	970	28	1059
5	4.00	4.00	4.00	4.00	3.96	3.84	1.2	10.0	1.3	19.5	1.3	27.1	13	344	14	984	14	1073
0	4.00	4.00	4.00	4.00	4.00	4.00	1.2	11.2	1.2	20.7	1.2	22.3	4	348	4	988	4	1077
600 TON TRAIN																		
60			—			—					—	—					—	—
55			2.53			2.53					2.0	2.0					169	169
50			2.41			2.47					2.0	4.0					159	323
45		2.58	2.38		2.58	2.39			1.9	1.9	2.1	6.1			132	132	146	469
40		2.57	2.37		2.57	2.37			1.9	3.8	2.1	8.2			119	251	131	600
35		2.60	2.39		2.58	2.38			1.9	5.7	2.1	10.3			105	356	115	715
30		2.70	[illegible]		[illegible]	[illegible]			1.9	7.6	2.0	12.3			91	447	100	816
25		2.93	2.70		2.81	2.60			1.8	9.4	1.9	14.2			73	520	77	892
20		3.23	3.02		3.08	2.86			1.6	11.0	1.7	15.9			53	573	56	948
15	4.00	3.58	3.39	4.00	3.40	3.20	1.3	1.3	1.5	12.5	1.6	17.5	33	33	39	612	41	989
10	4.00	3.86	3.90	4.00	3.72	3.64	1.3	2.6	1.3	13.8	1.4	18.9	24	57	24	636	26	1015
5	4.00	4.00	4.00	4.00	3.93	3.95	1.2	3.8	1.3	15.1	1.3	20.2	13	70	14	650	14	1129
0	4.00	4.00	4.00	4.00	4.00	4.00	1.2	5.0	1.2	16.3	1.2	21.4	4	74	4	654	4	1133
1000 TON TRAIN																		
40		—	—		—	—			—	—	—	—			—	—	—	—
35		.98	.79		.98	.79			5.1	5.1	6.3	6.3			280	280	346	346
30		1.00	.80		.99	.80			5.0	10.1	6.2	12.5			238	518	295	641
25		1.05	.85		1.02	.82			4.9	15.0	5.9	18.4			198	716	238	879
20		1.12	.93		1.08	.89			4.6	19.6	5.4	23.8			152	868	178	1057
15		1.25	1.04		1.18	.98			4.2	23.8	4.8	28.6			108	976	123	1180
10	1.56	1.37	1.18	1.56	1.31	1.11	3.2	3.2	3.8	27.6	4.2	32.8	59	59	70	1046	77	1257
5	1.56	1.37	1.18	1.56	1.37	1.18	3.2	6.4	3.7	31.3	4.2	37.0	35	94	41	1087	46	1303
0	1.56	1.37	1.18	1.56	1.37	1.18	3.2	9.6	3.6	34.9	4.2	41.2	12	10.6	13	1100	15	1318
2000 TON TRAIN																		
40			—			—					—	—					—	—
35			.79			.79					6.3	6.3					346	346
30			.80			.80					6.2	12.5					295	641
25		1.05	.85		1.05	.82			4.8	4.8	6.1	18.6			193	193	246	887
10		1.14	.93		1.09	.89			4.6	9.4	5.6	24.2			152	345	185	1072
15		1.35	1.04		1.20	.98			4.2	13.6	5.1	29.3			108	453	131	1203
10		1.38	1.18		1.31	1.11			3.8	17.4	4.5	33.8			70	523	83	1286
5		1.38	1.18		1.38	1.18			3.6	21.0	4.2	38.0			40	563	46	1332
0		1.38	1.18		1.38	1.18			3.6	24.6	4.2	42.2			13	576	15	1347

TABLE XVII.

TABLE XVII

LOCOMOTIVE NO. 4.

200 TON TRAIN

Speed M.P.H.	Available Tender D.B.P. in Lbs.			Available D.B.P. per Ton of Train – Lbs.			Resistance per Ton of Train – Lbs.			D.B.P. Available for Acceleration Lbs. per Ton			Acceleration in M.P.H. P.S.			Avg. Acceleration M.P.H. P.S.			Time Required to Produce Changes of Speed as Shown in Col. 1, – Sec.						Distance Travelled to Produce Changes of Speed as Shown in Col. 1, Feet					
	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Total	Level	Total	1% down Grade	Total	1% up Grade	Total	Level	Total	1% down Grade	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	21700	25600	29500	108.5	128.0	147.5	23.72	3.72	-16.28	84.8	124.3	168.8	.90	1.32	1.74	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	21640	25540	29440	108.2	127.7	147.2	24.00	4.00	-16.00	84.2	123.7	163.2	.90	1.32	1.74	.90	1.32	1.74	5.6	5.6	3.8	3.8	2.9	2.9	62	62	42	42	32	32
15	20560	24460	28360	102.8	122.3	141.8	24.34	4.34	-15.66	78.5	118.0	157.5	.84	1.26	1.68	.87	1.29	1.71	5.7	11.3	3.9	7.7	2.9	5.8	105	167	72	114	32	64
20	17750	21650	25550	88.8	108.3	127.8	24.74	4.74	-15.26	64.1	103.6	147.1	.68	1.11	1.52	.76	1.19	1.60	6.6	17.9	4.2	11.9	3.1	8.9	170	337	108	222	80	144
25	13630	17530	21430	68.2	87.7	107.2	25.20	5.20	-14.80	43.0	82.5	122.0	.46	.88	1.30	.57	1.00	1.41	8.8	26.7	5.0	16.3	3.5	12.4	291	628	165	387	116	260
30	10910	14810	18710	54.6	74.1	93.6	25.72	5.72	-14.28	28.9	68.4	107.9	.31	.73	1.15	.39	.81	1.23	12.8	39.5	6.2	23.1	4.1	16.5	517	1145	250	637	165	425
35	8590	12490	16390	49.0	62.5	82.0	26.28	6.28	-13.72	16.7	56.2	95.7	.18	.60	1.02	.25	.67	1.09	20.0	59.5	7.5	30.6	4.6	21.1	954	2099	358	995	219	644
40	6700	10600	14500	37.5	53.0	72.5	26.94	6.94	-13.06	6.6	46.1	85.6	.07	.49	.91	.13	.55	.97	38.4	97.9	9.1	39.7	5.1	26.2	2110	4209	500	1495	280	924
45	5120	9020	12920	25.6	45.1	64.6	27.60	7.60	-12.40		37.5	77.0		.40	.82		.45	.87			11.1	50.8	5.7	31.9			692	2187	356	1280
50	3620	7520	11420	18.1	37.6	57.1	28.40	8.40	-11.60		29.2	68.7		.31	.73		.36	.78			13.9	64.7	6.4	38.3			970	3157	446	1726
55	2490	6390	10290	12.5	32.0	51.5	29.28	9.28	-10.72		22.7	62.2		.24	.66		.28	.70			17.8	82.5	7.1	45.4			1370	4527	547	2273
60	1390	5290	9190	7.0	26.5	46.0	30.10	10.10	-9.90		16.4	55.9		.18	.68		.21	.63			23.8	106.3	8.0	53.4			2010	6537	674	2947

600 TON TRAIN

Speed M.P.H.	Available Tender D.B.P. in Lbs.			Available D.B.P. per Ton of Train – Lbs.			Resistance per Ton of Train – Lbs.			D.B.P. Available for Acceleration Lbs. per Ton			Acceleration in M.P.H. P.S.			Avg. Acceleration M.P.H. P.S.			Time Required to Produce Changes of Speed as Shown in Col. 1, – Sec.						Distance Travelled to Produce Changes of Speed as Shown in Col. 1, Feet					
	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Total	Level	Total	1% down Grade	Total	1% up Grade	Total	Level	Total	1% down Grade	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	21700	25600	29500	36.2	42.7	49.2	23.72	3.72	-16.28	12.5	39.0	65.5	.13	.41	.68	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	21640	25540	29440	36.1	42.6	49.1	24.00	4.00	-16.00	12.1	38.6	65.1	.13	.40	.68	.13	.41	.68	38.4	38.4	12.2	12.2	7.3	7.3	423	423	134	134	80	80
15	20560	24460	28360	34.3	40.8	47.3	24.34	4.34	-15.66	10.0	36.5	63.0	.10	.38	.66	.12	.39	.67	41.6	80.0	12.8	25.0	7.5	14.8	796	1179	235	369	138	218
20	17750	21650	25550	29.6	36.1	42.6	24.74	4.74	-15.26	4.9	31.4	57.9	.05	.33	.60	.08	.36	.63	62.5	142.5	13.9	38.9	7.9	22.7	1602	2781	357	726	205	423
25	13630	17530	21430	22.7	29.2	35.7	25.20	5.20	-14.80		24.0	50.5		.25	.53		.29	.57			17.2	56.1	8.8	31.5			568	1294	291	714
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		19.0	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	41.5			[illegible]	[illegible]	[illegible]	[illegible]
35	8590	12490	16390	14.3	20.8	27.3	26.28	6.28	-13.72		14.5	41.0		.15	.43		.18	.45			27.8	105.6	11.1	52.6			1375	3545	530	1847
40	6700	10600	14500	11.2	17.3	24.2	26.94	6.94	-13.06		10.4	37.3		.11	.39		.13	.41			38.4	144.0	12.2	64.8			2110	5655	671	2318
45	5120	9020	12920	8.5	15.0	21.5	27.60	7.60	-12.40		7.4	37.9		.08	.35		.10	.37			50.0	194.0	13.5	78.3			3120	8775	842	3160
50	3620	7520	11420	6.0	12.5	19.0	28.40	8.40	-11.60		4.1	30.6		.04	.32		.06	.34			83.3	277.3	14.7	93.0			5800	14575	1024	4184
55	2496	6390	10290	4.2	10.7	17.2	29.28	9.28	-10.72		1.4	27.9		.01	.29		.02	.31			166.7	444.0	16.1	109.1			2840	17415	1240	5424
60	1396	5290	9190	2.3	8.8	15.3	30.10	10.10	-9.90			25.2			.26			.28					17.8	126.9					1500	6924

1000 TON TRAIN

Speed M.P.H.	Available Tender D.B.P. in Lbs.			Available D.B.P. per Ton of Train – Lbs.			Resistance per Ton of Train – Lbs.			D.B.P. Available for Acceleration Lbs. per Ton			Acceleration in M.P.H. P.S.			Avg. Acceleration M.P.H. P.S.			Time Required to Produce Changes of Speed as Shown in Col. 1, – Sec.						Distance Travelled to Produce Changes of Speed as Shown in Col. 1, Feet					
	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Total	Level	Total	1% down Grade	Total	1% up Grade	Total	Level	Total	1% down Grade	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—			—	—	—	—			—	—	—	—
5	21700	25600	29500	21.7	25.6	29.5	24.01	4.01	-15.99		21.6	45.5		.23	.48		—	—			—	—	—	—			—	—	—	—
10	21640	25540	29440	21.6	25.5	29.4	24.27	4.27	-15.73		21.2	45.1		.23	.48		.23	.48			21.7	21.7	10.4	10.4			239	239	114	114
15	20560	24460	28360	20.6	24.5	28.4	24.60	4.60	-15.40		19.9	47.8		.21	.47		.22	.50			22.7	44.4	10.0	20.8			416	655	191	305
20	17750	21650	25550	17.8	21.7	25.6	25.00	5.00	-15.00		16.7	40.6		.18	.48		.20	.45			26.0	69.4	11.1	31.9			641	1296	285	590
25	13630	17530	21430	13.6	17.5	21.4	25.47	5.47	-14.53		12.0	35.9		.13	.38		.16	.41			31.2	100.6	12.2	44.1			1030	2326	403	993
30	10910	14810	18710	10.9	14.8	18.7	26.00	6.00	-14.00		8.8	32.1		.09	.35		.11	.37			45.4	146.0	18.5	57.6			1832	4158	545	1538
35	8590	12490	16390	8.6	12.5	16.4	26.62	6.62	-13.38		5.9	29.8		.06	.32		.08	.34			62.5	208.5	14.7	72.3			2980	7138	700	2238
40	6700	10600	14500	6.7	10.6	14.5	27.30	7.30	-12.70		3.3	27.2		.04	.29		.05	.31			100.0	300.5	16.1	88.4			5500	12638	886	3124

2000 TON TRAIN

Speed M.P.H.	Available Tender D.B.P. in Lbs.			Available D.B.P. per Ton of Train – Lbs.			Resistance per Ton of Train – Lbs.			D.B.P. Available for Acceleration Lbs. per Ton			Acceleration in M.P.H. P.S.			Avg. Acceleration M.P.H. P.S.			Time Required to Produce Changes of Speed as Shown in Col. 1, – Sec.						Distance Travelled to Produce Changes of Speed as Shown in Col. 1, Feet					
	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Total	Level	Total	1% down Grade	Total	1% up Grade	Total	Level	Total	1% down Grade	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	—	—	—	—	—	—	—	—	—	—	—	—		—	—		—	—					—	—			—	—	—	—
5	21700	25600	29500	10.9	12.8	14.8	24.01	4.01	-15.99		8.8	30.8		.09	.33		.09	.33					—	—			—	—	—	—
10	21640	25540	29440	10.8	12.8	14.7	24.27	4.27	-15.73		8.5	30.4		.09	.32		.09	.32					.09	.33			55.5	55.5	15.1	15.1
15	20560	24460	28360	10.3	12.2	14.2	24.60	4.60	-15.40		7.6	29.6		.08	.32		.08	.32					.09	.32			55.6	111.0	15.6	30.7
20	17750	21650	25550	8.9	10.8	12.8	25.00	5.00	-15.00		5.8	27.8		.06	.30		.06	.30					.07	.71			71.4	182.4	16.1	46.8
25	13630	17530	21430	6.8	8.8	10.7	25.47	5.47	-14.53		3.3	26.2		.00	.27		.04	.27					.05	.29			100.0	282.4	17.2	64.0
30	10910	14810	18710	5.5	7.4	9.4	26.00	6.00	-14.00		1.4	23.4		.01	.25		.01	.25					.03	.26			166.7	449.1	19.2	83.2
35	8590	12490	16390	4.3	6.2	8.2	26.62	6.62	-13.38			21.6			.23			.23						.24					20.8	104.0
40	6700	10600	14500	3.8	5.3	7.3	77.30	7.30	-12.70			20.0			.21			.21						.22					22.7	126.9

200 TON TRAIN

Speed M.P.H.	Retardation in M.P.H.P.S.			Avg. Retardation in M.P.H.P.S.			Time Required to Produce Changes of Speed as Shown in Col. 1, – Sec.						Distance Traveled to Produce Changes of Speed as Shown in Col. 1, – Sec.					
	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Total	Level	Total	1% down Grade	Total	1% up Grade	Total	Level	Total	1% down Grade	Total
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
60		1.88	1.67		1.90	1.70			—	—	—	—			—	—	—	—
55		1.82	1.61		1.85	1.69			2.7	2.7	3.0	3.0			228	228	253	253
50		1.78	1.57		1.80	1.59			2.8	2.8	3.1	6.1			216	444	239	492
45		1.76	1.55		1.77	1.56			2.8	8.4	3.2	9.3			195	639	223	715
40		1.77	1.55		1.76	1.55			2.8	11.2	3.2	12.5			175	814	200	915
35	2.71	1.78	1.58	2.71	1.77	1.56	1.8	1.8	2.8	14.0	3.2	15.7	99	99	154	968	176	1091
30	3.14	1.85	1.64	2.92	1.81	1.61	1.7	3.5	2.8	16.8	3.1	18.8	81	180	134	1102	148	1239
25	3.30	1.95	1.76	3.22	1.90	1.70	1.6	5.1	2.6	19.4	2.9	21.7	65	245	105	1207	117	1356
20	3.56	2.12	1.90	3.48	2.03	1.83	1.5	6.6	2.5	21.9	2.7	24.4	50	295	83	1290	90	1446
15	3.90	2.31	2.10	3.73	2.22	2.00	1.3	7.9	2.3	24.2	2.5	26.9	34	329	59	1349	64	1510
10	4.00	2.65	2.40	3.95	2.48	2.26	1.3	9.2	2.0	26.2	2.2	29.1	24	353	37	1386	40	1550
5	4.00	3.12	2.92	4.00	2.89	2.86	1.3	10.5	1.7	27.9	1.9	31.0	14	367	19	1405	21	1571
0	4.00	3.50	3.00	4.00	3.31	2.96	1.2	11.7	1.5	29.4	1.7	32.7	4	371	6	1411	6	1577

600 TON TRAIN

Speed M.P.H.	Retardation in M.P.H.P.S.			Avg. Retardation in M.P.H.P.S.			Time Required to Produce Changes of Speed as Shown in Col. 1, – Sec.						Distance Traveled to Produce Changes of Speed as Shown in Col. 1, – Sec.					
	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Total	Level	Total	1% down Grade	Total	1% up Grade	Total	Level	Total	1% down Grade	Total
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
60			1.75			1.78					—	—					—	—
55			1.68			1.72					2.9	2.9					245	245
50		2.62	1.64		2.62	1.66			1.9	1.9	3.0	5.9			146	146	231	476
45		2.59	1.57		2.60	1.60			1.9	3.8	3.1	9.0			132	278	216	692
40		2.59	1.57		2.59	1.57			1.9	5.7	3.2	12.2			118	396	200	892
35		2.62	1.65		2.60	1.60			1.9	7.6	3.1	15.3			105	501	170	1062
30		[illegible]	[illegible]		[illegible]	[illegible]			[illegible]	[illegible]	3.0	18.3			[illegible]	[illegible]	143	1205
25		2.91	1.84		2.81	1.77			1.8	11.3	2.8	21.1			73	665	113	1318
20		3.22	1.99		3.06	1.91			1.6	12.9	2.6	23.7			53	718	86	1404
15	3.81	3.60	2.19	3.81	3.41	2.09	1.3	1.3	1.5	14.4	2.4	26.1	33	33	39	757	68	1466
10	4.00	4.00	2.51	3.91	3.80	2.35	1.3	2.6	1.3	15.7	2.1	28.2	24	57	24	781	39	1505
5	4.00	4.00	3.05	4.00	4.00	2.78	1.2	3.8	1.3	17.0	1.8	30.0	13	70	14	795	20	1525
0	4.00	4.00	3.14	4.00	4.00	3.10	1.2	5.0	1.2	18.2	1.6	31.6	4	74	4	800	6	1531

1000 TON TRAIN

Speed M.P.H.	Retardation in M.P.H.P.S.			Avg. Retardation in M.P.H.P.S.			Time Required to Produce Changes of Speed as Shown in Col. 1, – Sec.						Distance Traveled to Produce Changes of Speed as Shown in Col. 1, – Sec.					
	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Total	Level	Total	1% down Grade	Total	1% up Grade	Total	Level	Total	1% down Grade	Total
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
40		—	—		—	—			—	—	—	—			—	—	—	—
35		.97	.75		.97	.75			5.2	5.2	6.7	6.7			285	285	369	369
30		1.00	.79		.99	.77			5.1	10.3	6.5	13.2			246	531	310	679
25		1.05	.83		1.03	.81			4.9	15.2	6.2	19.4			198	729	250	929
20		1.13	.90		1.09	.87			4.6	19.8	5.8	25.2			152	881	191	1120
15		1.25	1.02		1.19	.96			4.2	24.0	5.2	30.4			108	989	134	1254
10		1.37	1.17		1.31	1.09			3.8	27.8	4.6	35.0			70	1059	85	1339
5		1.40	1.17		1.39	1.17			3.6	31.4	4.3	39.3			40	1099	47	1386
0		1.40	1.17		1.40	1.17			3.6	35.0	4.3	43.6			13	1112	16	1402

2000 TON TRAIN

Speed M.P.H.	Retardation in M.P.H.P.S.			Avg. Retardation in M.P.H.P.S.			Time Required to Produce Changes of Speed as Shown in Col. 1, – Sec.						Distance Traveled to Produce Changes of Speed as Shown in Col. 1, – Sec.					
	1% up Grade	Level	1% down Grade	1% up Grade	Level	1% down Grade	1% up Grade	Total	Level	Total	1% down Grade	Total	1% up Grade	Total	Level	Total	1% down Grade	Total
32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
40											—	—					—	—
35			.76			.76					6.6	6.6					363	363
30			.80			.78					6.4	13.0					305	668
25		1.07	.84		1.07	.82			4.7	4.7	6.1	19.1			190	190	246	914
20		1.15	.91		1.11	.87			4.5	9.2	5.8	24.9			149	339	192	1106
15		1.27	1.03		1.21	.97			4.1	13.3	5.2	30.1			105	444	134	1240
10		1.39	1.19		1.33	1.11			3.8	17.1	4.5	34.6			70	514	83	1323
5		1.42	1.19		1.40	1.19			3.6	20.7	4.2	38.8			40	554	46	1369
0		1.42	1.19		1.42	1.19			3.5	24.2	4.2	43.0			13	567	15	1384

APPENDIX V.

WATER AND COAL CONSUMPTION.

WATER CONSUMPTION.

Water consumption varies greatly with the conditions of operation. The amount of water used per unit of time when a boiler is working to its limit, is constant for different speeds, if these speeds are above the maximum speed where boiler pressure can be maintained with full cut-off. If these speeds are below the maximum speed where boiler pressure can be maintained with full cut-off, then the water consumption varies directly with the speed.

Reference to Figures 33, 34, 35, and 36, will make clear the statements made in the above paragraph. For example, let us see how Fig. 35 is developed. This figure represents the water and coal consumption for locomotive No. 3, a few of whose dimensions are as follows:

Diameter of drivers = 63 inches;
Cylinder diameter = 24 inches;
Cylinder stroke = 30 inches;
Boiler pressure = 200 pounds, gauge;
Heating surface = 3614 square feet;
Volume of each cylinder = 7.83 cubic feet.

From a previous discussion on rates of evaporation in Appendix I, Locomotive Tractive Effort, it is reasonable to expect 11.5 pounds of equivalent evaporation as a maximum for each square foot of heating surface per hour. At this rate, the maximum amount of actual steam generated and used per minute without a drop in the boiler pressure, is:

$$\frac{11.5 \times 3614}{1.2 \times 60} = 578 \text{ pounds (considering feed water}$$

temperature of 60° F.).

For one revolution of the drivers, assuming that for both the large wheel and the small wheel engines the valve gear is so designed that a maximum cut-off of 88.0% is obtained, and that the quality of the steam in the cylinders at cut-off is 80%, the steam consumption when the maximum tractive effort is based on cylinder power, is calculated as follows:

From steam tables, the weight of one cubic foot of steam in the cylinders at 200 x 95%, or 190 pounds gauge pressure per square inch, is 0.447 pounds. The weight of one cubic foot of water at a temperature of 384° F. corresponding to 190 pounds steam pressure, is 54.19 pounds. By assumption, one pound of the mixture of steam and water contains 0.80 pounds of steam and 0.20 pounds of water, therefore 0.80/.447 plus 0.20/54.19 gives a total volume of 1.7907 cubic feet for one pound of the mixture. The number of pounds of the mixture required for one revolution of the drivers, is:

$$\frac{7.83 \times 4 \times .88}{1.7907} = 15.28$$

No allowance is made for clearance, as it is assumed that pressure due to compression is equal to the initial pressure at cut-off. From the calculations, it is evident that the volume at cut-off represents the quantity of the mixture of steam and water used in one stroke. Now, the maximum train speed at full cut-off (88%) where full boiler pressure can be

LOCOMOTIVE NO. 1.

830 H.P.

DIAM. DRIVERS	86"	BOILER PRESSURE	190 LB.
CYLINDER DIAM.	19"	HEATING SURFACE	1930 SQ. FT.
CYLINDER STROKE	24"	VOLUME OF EACH CYL.	3.94 CU. FT.

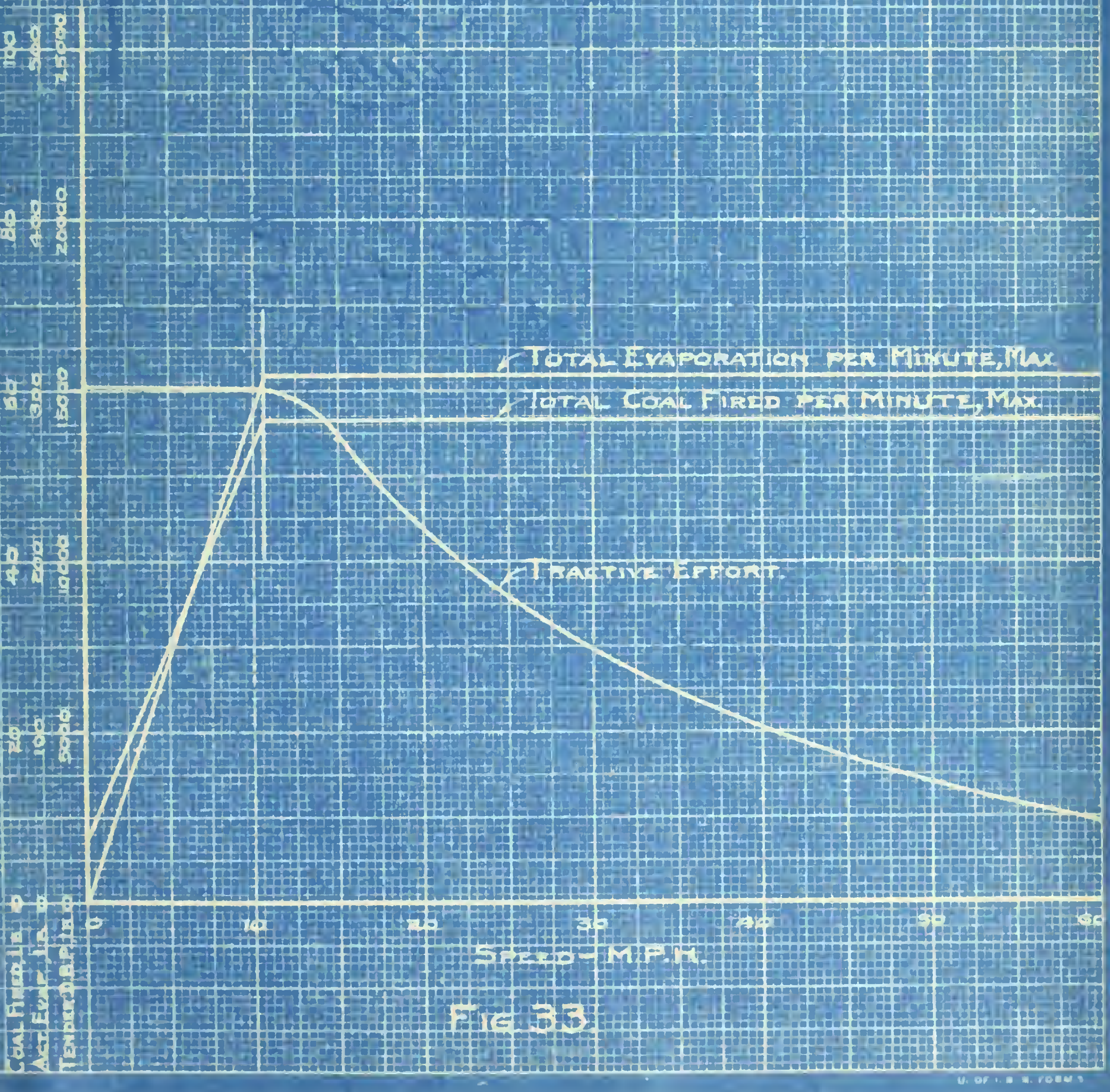
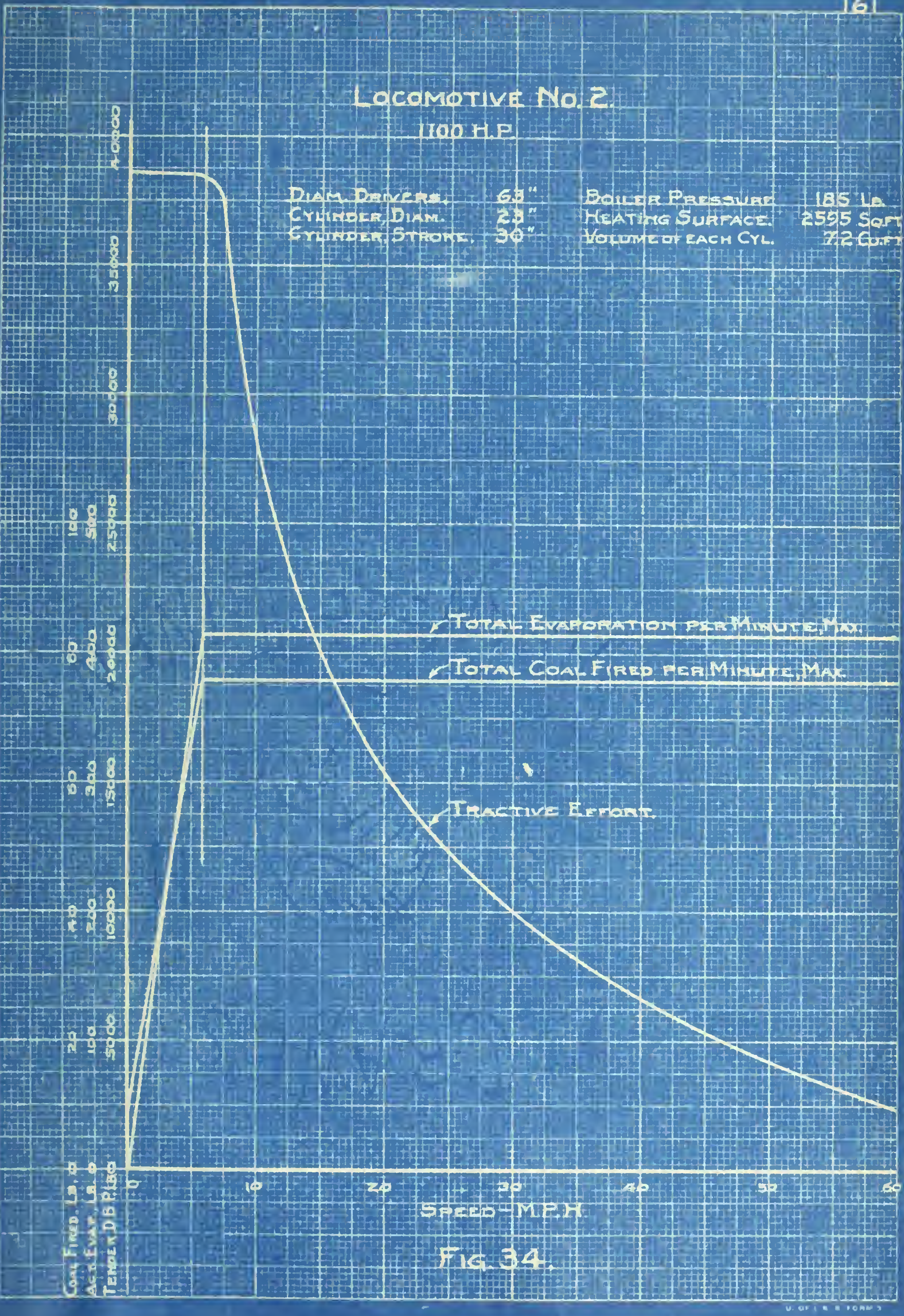


FIG. 33.



LOCOMOTIVE NO. 2.

1100 H.P.

DIAM. DRIVERS.	63"	BOILER PRESSURE	185 LB.
CYLINDER, DIAM.	23"	HEATING SURFACE.	2595 SQFT
CYLINDER, STROKE.	30"	VOLUME OF EACH CYL.	7.2 CU.FT

FIG. 34.

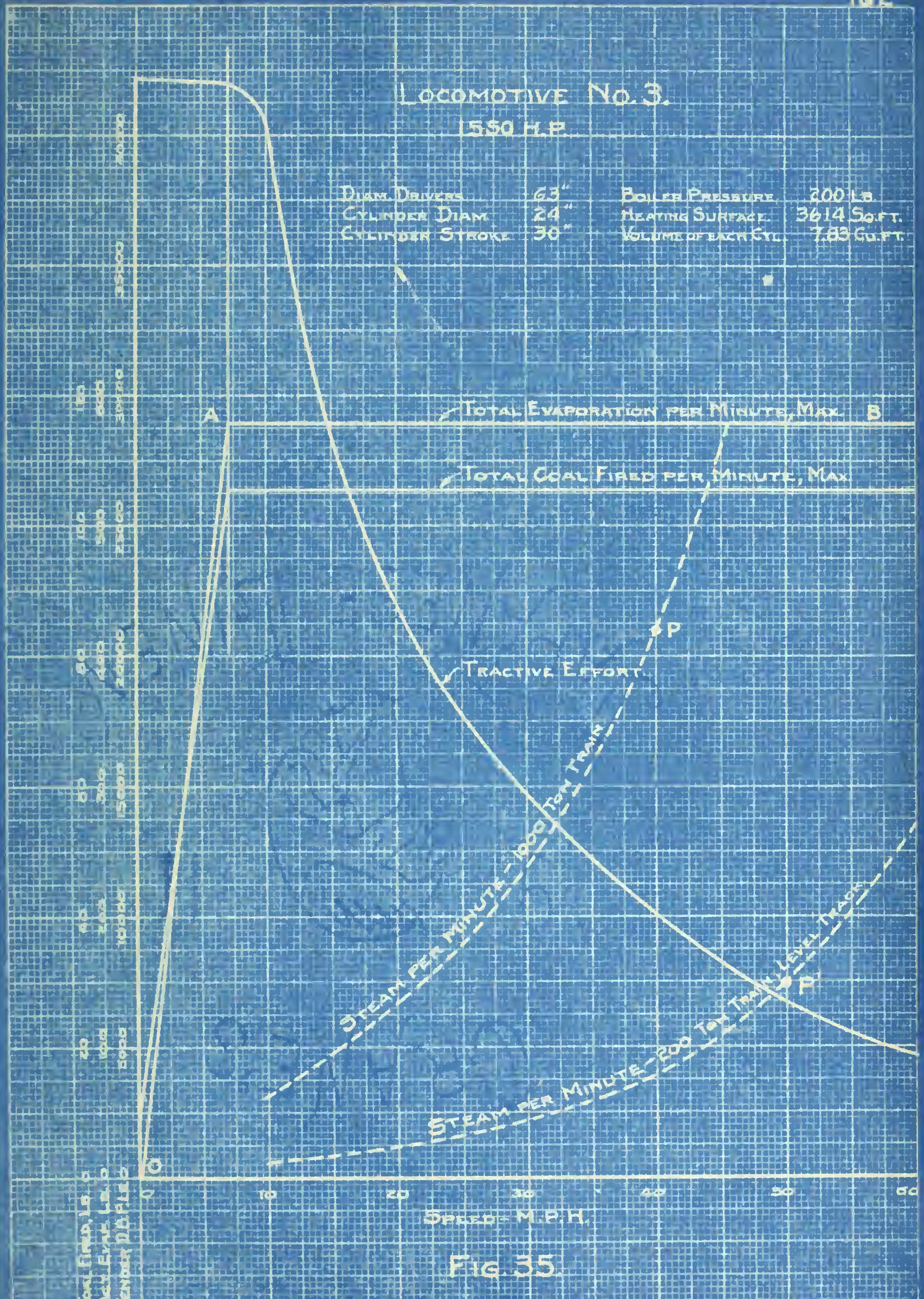

LOCOMOTIVE No. 3.
1550 H.P.
DIAM. DRIVERS 63"
CYLINDER DIAM. 24"
CYLINDER STROKE 30"
BOILER PRESSURE 200 LB.
HEATING SURFACE 3614 SQ. FT.
VOLUME OF EACH CYL. 7.85 CU. FT.
A
TOTAL EVAPORATION PER MINUTE, MAX.
B
TOTAL COAL FIRED PER MINUTE, MAX.
P
TRACTIVE EFFORT
STEAM PER MINUTE – 1000 TON TRAIN
STEAM PER MINUTE – 200 TON TRAIN, LEVEL TRACK
P
O
COAL FIRED, LB.
ACT. EVAP. LB.
TRACTIVE EFFORT, LB.
0
20
40
60
80
100
120
0
100
200
300
400
500
600
0
5000
10000
15000
20000
25000
30000
35000
40000
0
10
20
30
40
50
60
SPEED – M.P.H.

FIG. 35.

LOCOMOTIVE NO. 4.

1550 H.P.

DIAM. DRIVERS	80"	BOILER PRESSURE	205 LB.
CYLINDER DIAM.	22"	HEATING SURFACE	3582 SQ. FT.
CYLINDER STROKE	26"	VOLUME EACH CYL.	5.72 CU. FT.

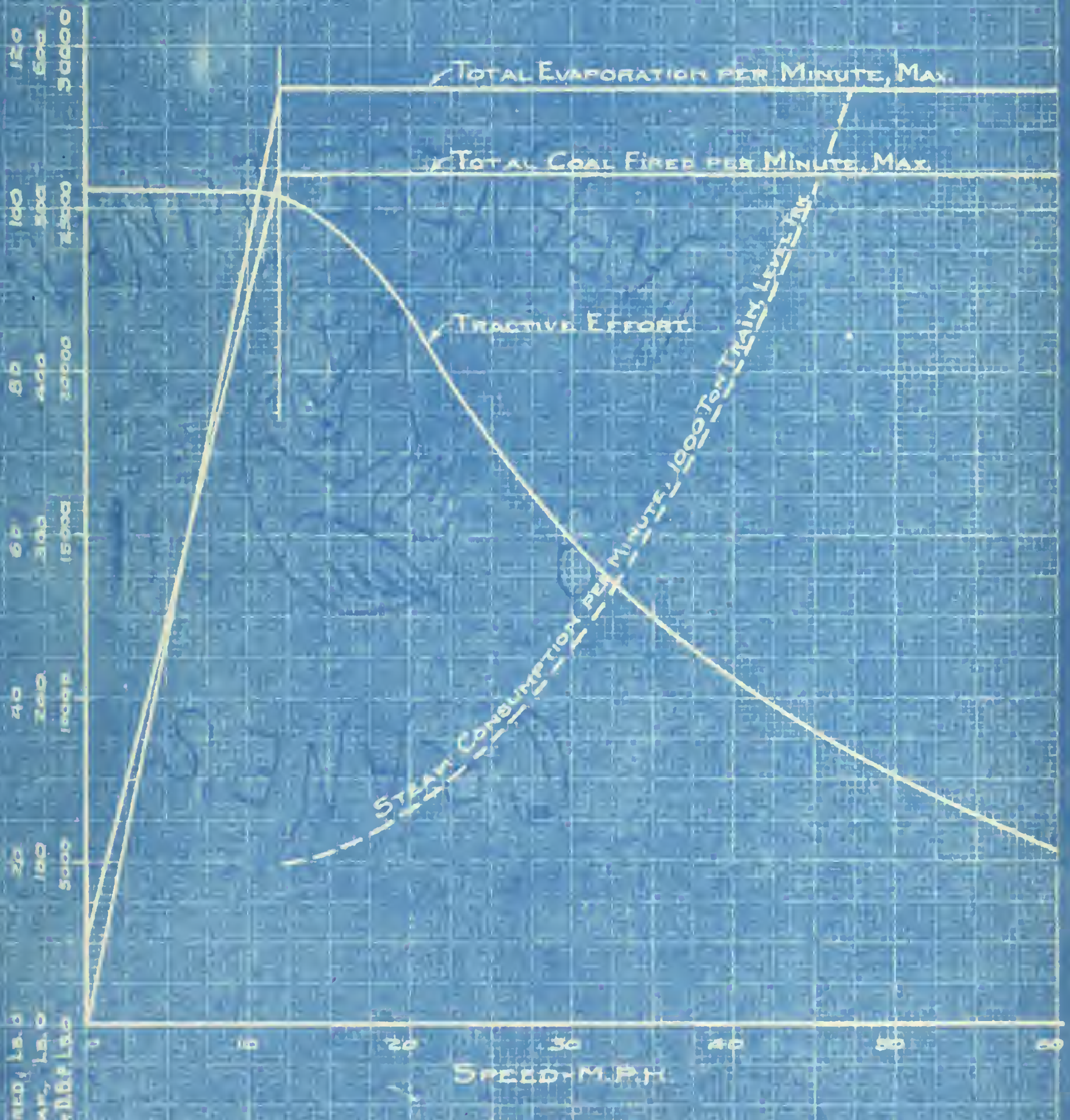


FIG. 36.

maintained, is:

$$\frac{578}{15.28} = 37.8 \text{ revolutions per minute.}$$

This maximum train-speed converted into miles per hour, gives 7.09.

At one-half, or at $\frac{1}{x}$ of the maximum speed at full cut-off, as at 3.55 or at $\frac{7.09}{x}$ miles per hour, the steam consumption would be one-half, or $\frac{1}{x}$, as great; or, in other words, the steam consumption from zero speed to that speed where the cylinders can develop maximum tractive effort without exhausting the boiler, varies as a straight line, as is shown by the line OA in Fig. 35. For other speeds, it is obvious that the maximum cut-off for a particular speed will require a steam consumption equal to the amount that the boiler can generate without a decrease in boiler pressure. This is represented by the line AB in Fig. 35.

For ordinary conditions of operation, it is unusual for a locomotive to work under maximum power conditions for long periods of time; generally about 30 minutes can be taken as a maximum limit of time except in mountainous regions. For this reason, it becomes necessary to develop a process for determining the steam consumption for such periods of average operation.

If the effect of changes in the rate of evaporation and in the quality of the steam in the cylinder at different cut-offs is neglected, and the advantage gained by permitting

a given amount of steam to work expansively, as at short cut-offs, is also neglected, it seems reasonable to expect the tractive effort to be a reliable measure of the power to which the boiler is worked. Under these assumptions, we may consider that the ratio of the required tender draw-bar pull to the available tender draw-bar pull, for any speed and any train in question, gives the per cent of maximum power to which the boiler is worked. Expressed as a fractional ratio, we have

$$\frac{\text{Required T.D.B.P.}}{\text{Available T.D.B.P.}} = \text{Approximate per cent of}$$

maximum power to which the boiler is worked.

As shown by Fig. 35, the steam consumption has been based upon a unit of time, viz., the minute. For the problem in hand, it is convenient to take the time required for any certain locomotive to exert power on a train from the speed-time curves as shown in Figures 29, 30, 31, and 32.

It is obvious that the maximum steam consumption per minute is constant when the boiler is working to its capacity, or when the engine is running at its maximum speed and the capacity of the boiler is taxed. At low speeds the engine may be working to a maximum, but the boiler may be working much below its capacity. In such instances where acceleration is taking place, the steam consumption is based on the average speed during that period of acceleration. In other words, if "S" is the value of the steam consumption at the speed "V"

where the boiler is just able to supply steam at maximum cut-off, and since it is obvious that the steam consumption at zero speed is zero, then the average amount of steam used during acceleration to the speed "V", is $\frac{S}{2}$.

Accordingly, to find the steam consumption for any locomotive at the head of a train for maximum conditions of operation, first take the steam consumption during the time the locomotive has its maximum tractive effort determined by the cylinders and add to this the steam consumption during the period that the maximum tractive effort is determined by the evaporative power of the boiler.

For those conditions of operation where the boiler and engine are not worked to a maximum, the determination of the steam consumption for lesser rates of power is here accomplished by the use of the following equation:

(Maximum evaporation per minute, pounds) x
(Required tender draw-bar pull, pounds) ÷
(Available tender draw-bar pull, pounds) =
Steam consumption per minute at a constant speed, pounds, for a particular locomotive and train in question.

For example, by reference to Table XVI, which shows in tabular form the accelerations and retardations for locomotive No. 3 when handling the four trains required by the problem, we find that the 200 ton passenger train and the 1000 ton freight train can be hauled on level track at speeds

which are in excess of the limits assigned by the conditions of the problem. Therefore, to haul these trains on level track at speeds within the limits imposed by the problem, both the engine and boiler are required to work at a lesser power. For instance, since the locomotive is what is termed a "small driver" locomotive, its speed is limited to 60 miles per hour. The required tender draw-bar pull for the 200 ton train at a constant speed of 50 miles per hour, is 1680 pounds, as shown in column 9, Table XVI. At this speed the locomotive is capable of developing an available tender draw-bar pull of 6740 pounds, as shown in column 3 in the same table, which necessitates a maximum actual steam consumption of 578 pounds per minute, as has been heretofore determined. Now, the expression for steam consumption at this low power is:

$$578 \times \frac{1680}{6740} = 145 \text{ pounds per minute.}$$

This determines the point P' shown in Fig. 35, on the steam consumption curve for locomotive No. 3 and the 200 ton train while running at a constant speed of 50 miles per hour on level tangent track. All other points on this curve are determined in the same manner.

The steam consumption curve for locomotive No. 3 and 1000 ton freight train for low rates of power, is determined by the same method cited above. But with this problem, the speed limit imposed is 40 miles per hour, therefore by Table XVI, column 12, it is evident that the tender draw-bar pull available

for acceleration is sufficient to develop a speed of 45 miles per hour with maximum boiler conditions. The required tender D.B.P. for this 1000 ton train for a constant speed of 40 miles per hour, is 7300 pounds, as shown in column 9, Table XVI. At this speed the locomotive is capable of developing an available tender D.B.P. of 10090 pounds, as shown in column 3 in the above mentioned table, which necessitates a maximum steam consumption of 578 pounds per minute, as has been heretofore determined. Now, the expression for steam consumption at this low power is:

$$578 \times \frac{7300}{10090} = 418 \text{ pounds per minute.}$$

This determines the point P shown in Fig. 35, on the steam consumption curve for locomotive No. 3, and the 1000 ton train while running at a constant speed of 40 miles per hour on level tangent track. All other points on this curve are determined in the same manner.

All steam consumption curves for less than maximum rates of power, for the four locomotives and four trains under different conditions of grade as considered in this article, have been determined by the method outlined in the previous discussion. Thus we have a simple means of determining the water consumption at any power and speed for any locomotive and train.

The following tables for water consumption have been prepared by the method previously outlined. They represent the water consumption for the program of runs as outlined in the beginning of this article.

TABLE XVIII.

WATER CONSUMPTION, pounds, FOR LOCAL SCHEDULE.

Stations	Distance between stops. Miles.	Water Consumed, lbs. Locomotive Numbers 1	2	3	4
		200 ton train			
A	0	0	0	0	0
B	0.5	316	380	438	430
C	1.0	517	664	755	710
D	1.5	691	872	1020	960
E	2.0	865	1087	1275	1210
F	3.0	935	1509	1547	1680
G	4.0	1020	1938	1819	2160
H	5.0	1850	2364	2091	2640
I	7.0	2460	3194	2635	3600
J	10.0	3370	4444	3451	5040
K	16.0	5220	6934	5083	7920
		600 Ton Train			
A	0	0	0	0	0
B	0.5	491	577	756	688
C	1.0	835	972	1164	1184
D	1.5	1112	1303	1614	1576
E	2.0	1370	1628	1959	1968
F	3.0	1865	2215	2654	2656
G	4.0	2320	2755	3349	3316
H	5.0	2780	3310	4044	3974
I	7.0	3686	4415	5430	5176
J	10.0	5076	6075	7514	7050
K	16.0	7856	9400	11664	10776

TABLE XVIII (continued)

WATER CONSUMPTION, pounds, FOR LOCAL SCHEDULE.

Stations	Distance between stops. Miles.	Water Consumed, lbs. Locomotive Numbers 1	2	3	4
		1000 ton train			
A	0	0	0	0	0
B	0.5	577	681	1120	850
C	1.0	990	1145	1705	1335
D	1.5	1338	1538	2175	1816
E	2.0	1655	1920	2530	2260
F	3.0	2260	2640	3390	3100
G	4.0	2890	3350	4020	3960
H	5.0	3500	4063	4650	4820
I	7.0	4740	5490	5910	6540
J	10.0	6590	7620	7800	9120
K	16.0	10290	11880	11580	14260
		2000 Ton Train			
A	0	0	0	0	0
B	0.5	704	892	1185	755
C	1.0	1368	1538	1850	1741
D	1.5	1906	2060	2515	2254
E	2.0	2416	2571	3082	3146
F	3.0	3386	3585	4257	4038
G	4.0	4316	4578	5490	5176
H	5.0	5656	5873	6647	6322
I	7.0	7096	7578	8965	8615
J	10.0	9876	10550	12420	12016
K	16.0	15406	16510	19350	18926

TABLE XIX.

WATER CONSUMPTION, pounds, FOR THROUGH SCHEDULE.

Train Weights	Locomotive Numbers 1	2	3	4
		1% UP GRADE.		
200 ton	31100	35105	43500	43166
600 "	*	82880	86912	86523
1000 "	*	*	115840	*
2000 "	*	*	*	*
		LEVEL TRACK.		
200 ton	15900	18060	13935	24840
600 "	23650	28100	35335	27772
1000 "	30920	35604	31920	31345
2000 "	47430	50420	58667	58532
		1% DOWN GRADE.		
200 ton	**950	**531	**520	**920
600 "	**1810	**1138	**1223	**2140
1000 "	**642	**725	**810	**840
2000 "	**820	**960	**1160	**1203

* Beyond capacity of locomotive.

** Required during acceleration only, as the grade is sufficient to keep the train running at maximum speed.

COAL CONSUMPTION.

For estimating the amount of coal consumed under maximum conditions of operation, it is necessary to refer to Table VIII in Appendix I, Part I, which fixes the maximum quantity of coal that can be economically fired in a boiler of specified proportions containing a given amount of heating surface.

Evidently for the case under consideration, the maximum amount of coal consumed per square foot of heating surface is 1.75 pounds. And according to the tractive effort formula, a rate of 11.5 pounds of equivalent evaporation may be expected for maximum conditions. This means that an evaporation of 6.6 pounds from and at 212°F. per pound of coal, or an actual evaporation of 5.5 pounds per pound of coal is to be expected for maximum conditions of operation. These figures appear rather low when compared with test plant data, but if compared to the results from road tests, it is seen that the figures here presented are representative of actual road conditions.

For lower power conditions, the amount of coal consumed depends on the amount of steam used, although not in a direct proportion. During operation at such rates of power, the amount of work performed per pound of steam is greater than at higher rates of power. Then again, the amount of steam generated per pound of coal is greater at low power than at high power. Locomotive fuel consumption

as affected by these two combinations of conditions, is not accurately determinate. An attempt at the solution of the problem is made by neglecting the first condition, and by correcting for the second.

As in the method outlined for determining water consumption, the ratio of the required tender draw-bar pull to the available tender draw-bar pull for a locomotive at the head of a certain train when running at a selected constant speed, gives the per cent of maximum power to which the boiler is worked. As stated before, the coal consumption is known for maximum power conditions; it only remains to correct for the law governing the increase in water evaporation per pound of coal for different rates of boiler power.

If we let the rate of evaporation per square foot of heating surface per hour, represent the rate of power to which a boiler is worked, then the curve in Fig. 38 represents the variation in the evaporation per pound of coal for different rates of power. The curve is based on a grade of coal equivalent to the coal used in determining the tractive effort of the locomotive in question. See Appendix I., Part II, for boiler operating conditions.

As stated before, the maximum rate of equivalent evaporation per square foot of heating surface is 11.5 pounds, therefore the curve AB shown in Fig. 37 can be plotted to new scales and given the form shown as curve AB in Fig. 38.

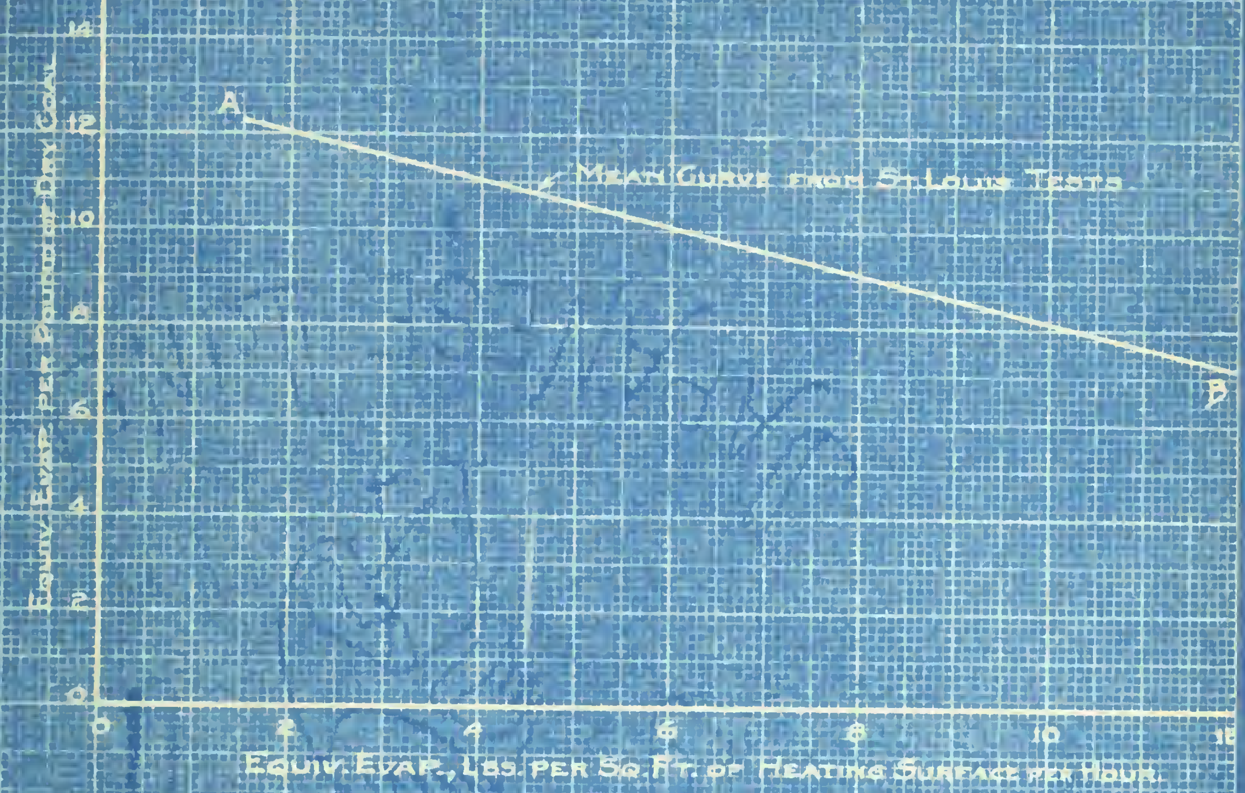


Fig. 37.

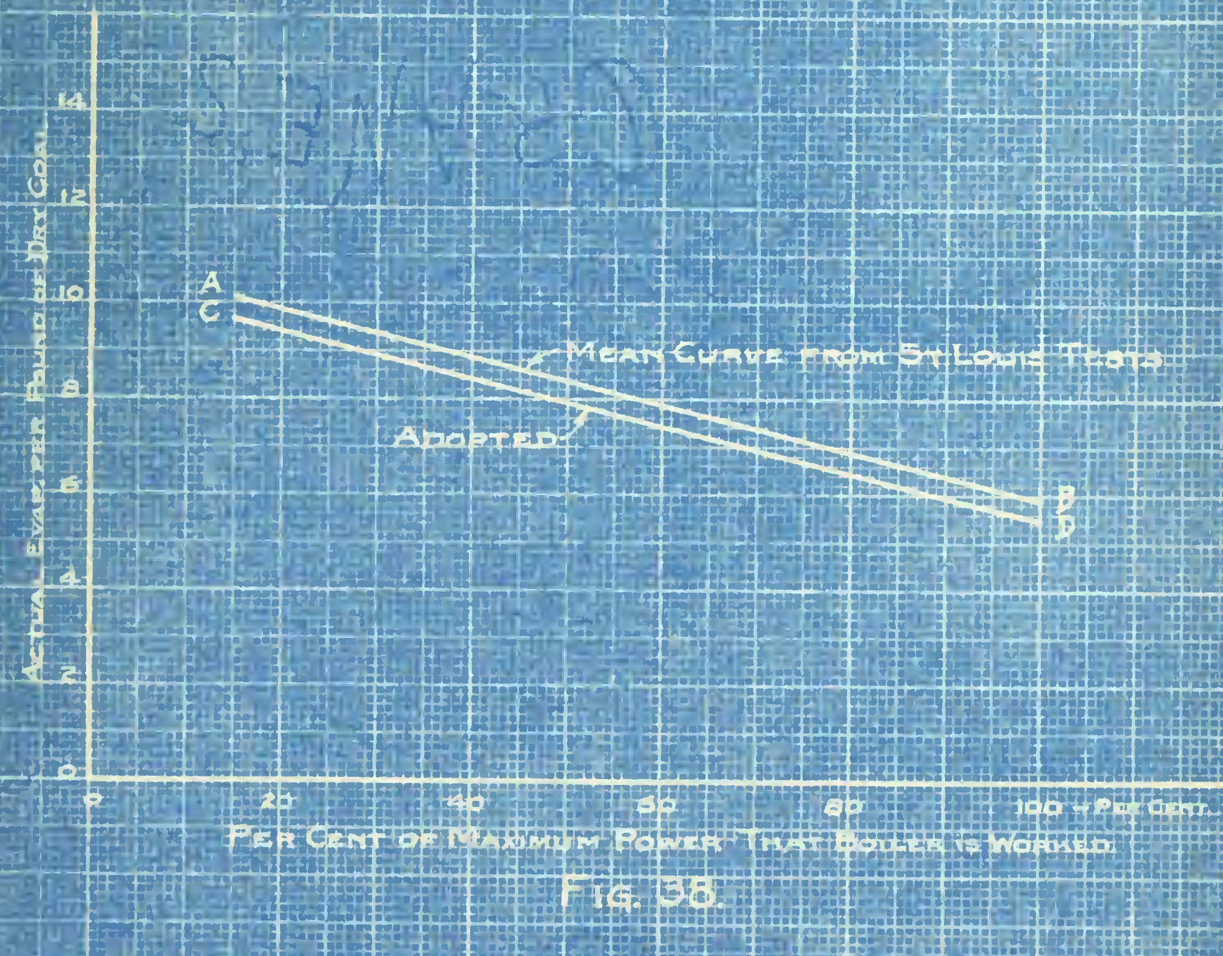


Fig. 38.

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Now, the problem under consideration has shown that at maximum rates of boiler operation, the actual evaporation per pound of coal is 5.5 pounds, therefore the point D has been taken so that its abscissa equals 100 per cent, and the corresponding ordinate is 5.5, and the curve CD has been drawn through the point D parallel to AB; or, in order words, the curve CD is drawn to have the same slope as AB.

The curve CD then represents the actual evaporation per pound of coal for the various rates of power that the boiler is worked.

To get the pounds of coal consumed when the boiler is working under less than maximum power conditions, first determine the per cent of maximum power that the boiler is worked, and then divide the water consumption as determined in a previous discussion, by the evaporation per pound of coal as given by the curve marked CD in Fig. 38.

The following tables for fuel consumption have been prepared by the method previously outlined. They represent the coal consumption for the series of runs outlined in the beginning of this article.

TABLE XX.

COAL CONSUMPTION, pounds, FOR LOCAL SCHEDULE.

Stations	Distance between stops. Miles.	Coal Consumed, lbs. Locomotive Numbers 1	2	3	4
		200 Ton Train			
A	0	0	0	0	0
B	0.5	58	70	80	78
C	1.0	97	122	137	129
D	1.5	134	159	186	174
E	2.0	162	199	220	220
F	3.0	224	276	254	306
G	4.0	280	354	288	393
H	5.0	338	432	322	480
I	7.0	543	584	398	655
J	10.0	618	812	500	917
K	16.0	952	1265	704	1440
		600 Ton Train			
A	0	0	0	0	0
B	0.5	91	105	138	124
C	1.0	154	177	212	215
D	1.5	204	238	296	286
E	2.0	251	297	357	357
F	3.0	342	405	484	482
G	4.0	424	504	610	602
H	5.0	509	604	737	721
I	7.0	677	807	990	940
J	10.0	931	1109	1368	1279
K	16.0	1437	1715	2127	1957

TABLE XX. (continued)

COAL CONSUMPTION, pounds, FOR LOCAL SCHEDULE.

Stations	Distance between stops. Miles.	Coal Consumed, lbs. Locomotive Numbers 1	2	3	4
		1000 Ton Train			
A	0	0	0	0	0
B	0.5	109	124	204	155
C	1.0	182	209	310	243
D	1.5	237	281	396	330
E	2.0	303	350	460	411
F	3.0	415	482	617	564
G	4.0	529	612	710	654
H	5.0	646	742	803	744
I	7.0	867	1002	989	924
J	10.0	1206	1390	1268	1194
K	16.0	1880	2166	1826	1734
		2000 Ton Train			
A	0	0	0	0	0
B	0.5	137	164	218	137
C	1.0	237	281	341	289
D	1.5	357	378	464	409
E	2.0	450	471	568	567
F	3.0	627	656	785	734
G	4.0	796	839	1012	941
H	5.0	1059	1020	1213	1148
I	7.0	1303	1382	1634	1565
J	10.0	1808	1929	2264	2188
K	16.0	2823	3021	3533	3440

TABLE XXI.

COAL CONSUMPTION, pounds, FOR THROUGH SCHEDULE.

Train Weights	Locomotive Numbers			
	1	2	3	4
		1% UP GRADE.		
200 ton	5660	6390	7910	7850
600 "	*	15050	15780	15720
1000 "	*	*	21080	*
2000 "	*	*	*	*
		LEVEL TRACK.		
200 ton	2890	2955	1748	4520
600 "	4300	5120	6430	5050
1000 "	5620	6480	5800	4592
2000 "	8630	9180	10660	10650
		1% DOWN GRADE.		
200 ton	**172	**97	**95	**167
600 "	**329	**207	**223	**389
1000 "	**116	**132	**147	**152
2000 "	**149	**174	**211	**219

* Beyond capacity of locomotive.

** Required during acceleration only, as the grade is sufficient to keep the train running at maximum speed.

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